UNITED STATES DISTRICT COURT
FOR THE WESTERN DISTRICT OF WISCONSIN

General Electric Company, GE Medical Systems (Norway) AS, GE Yokogawa Medical Systems, Ltd., GE Medical Systems Global Technology Company, LLC, GE Medical Systems, Ultrasound & Primary Care Diagnostics LLC, and GE Medical Systems, Inc. Plaintiffs, v. SONOSITE, INC. Defendant.	Case No. 07-C-0438-C **JURY DEMAND**

SECOND AMENDED COMPLAINT FOR PATENT INFRINGEMENT

Plaintiffs General Electric Company, GE Medical Systems (Norway) AS, GE Yokogawa Medical Systems, Ltd., GE Medical Systems Global Technology Company, LLC, GE Medical Systems, Ultrasound & Primary Care Diagnostics LLC, and GE Medical Systems, Inc. (collectively, "GE") by their attorneys, complain against Sonosite, Inc. ("Sonosite"), and allege as follows:

NATURE OF THE ACTION

This is an action arising under the United States Patent Laws, 35 U.S.C. § 1 *et. seq.*, including § 271. GE brings this action to seek damages and injunctive relief arising out Sonosite's infringement of GE's U.S. Patent Nos. 4,932,415 (the "'415 patent"), 5,584,294 (the "'294 patent"), 6,120,447 (the "'447 patent"), 6,210,327 (the "'327 patent"), 6,418,225 (the "'225 patent"), and 6,102,859 (the "'859 patent") (collectively, the "GE Patents-In-Suit," attached hereto at Exhibits A, B, C, D, E, and F respectively).

PARTIES

1. General Electric Company is a corporation organized and existing under the laws of the State of New York, having a principal place of business in Fairfield, Connecticut. General Electric Company is the assignee of the '447 patent, the '327 patent, the '859 patent, and the '225 patent.

2. GE Medical Systems (Norway) AS is a corporation organized and existing under the laws of Norway, having a principal place of business in Oslo, Norway. GE Medical Systems (Norway) AS is the assignee of the '415 patent.

3. GE Yokogawa Medical Systems, Ltd. is a corporation organized and existing under the laws of Japan, having a principal place of business in Tokyo, Japan. GE Yokogawa Medical Systems, Ltd. is the assignee of the '294 patent.

4. GE Medical Systems Global Technology Company, LLC is a corporation organized and existing under the laws of the State of Delaware, having a principal place of business in Waukesha, Wisconsin. GE Medical Systems Global Technology Company LLC is a licensee under the '294 patent with the sole right to enforce the '294 patent.

5. GE Medical Systems, Ultrasound & Primary Care Diagnostics LLC is a corporation organized and existing under the laws of the State of Delaware, having a principal place of business in Wauwatosa, Wisconsin. GE Medical Systems, Ultrasound & Primary Care Diagnostics LLC derives and reports revenue from the sale of ultrasound technology and services.

6. GE Medical Systems, Inc. is a corporation organized and existing under the laws of the State of Delaware, having a principal place of business in Pewaukee, Wisconsin. GE Medical Systems, Inc. derives and reports revenue from the sale of ultrasound technology and services.

7. GE Healthcare is a major business unit of General Electric Company. GE Healthcare is headquartered in Little Chalfont, United Kingdom. GE Healthcare's Clinical Systems division manufactures and sells a wide range of technologies and services for clinicians

and healthcare administrators, including ultrasound technologies and services. GE Healthcare's Clinical Systems division is based in Wauwatosa, Wisconsin.

8. On information and belief, Sonosite is a corporation organized and existing under the laws of the State of Washington, having a principal place of business at 21919 30th Drive SE, Bothell, WA 98021-3904.

JURISDICTION AND VENUE

9. Paragraphs 1 - 8 are incorporated by reference as if set forth here in full.

10. This Court has subject matter jurisdiction under 28 U.S.C. §§ 1331, 1338(a) because this case arises out of the federal patent laws 35 U.S.C. § 1, *et. seq*.

11. On information and belief, Sonosite regularly conducts business activities in this Judicial District. Such business activities include, on information and belief, the employment of at least one sales representative who regularly visits and solicits business in this District. In addition, on information and belief, Sonosite engages in other active solicitations of customers in this District and regularly sells infringing products in this District.

12. On information and belief, Sonosite also conducts and/or commissions research activities in this District. In 2005, on information and belief, Sonosite initiated a major research study conducted principally by individuals at the University of Wisconsin Medical School in Madison.

13. In addition, on information and belief, Sonosite regularly purchases equipment, materials and/or services from vendors located in this District, including the purchase of molded plastics from Contour Plastics of Baldwin, Wisconsin.

14. This Court thus may properly exercise personal jurisdiction over Sonosite pursuant to Wisconsin's long arm statute (Wis. Stat. § 801.05) and/or Rule 4(k)(2) of the Federal Rules of Civil Procedure.

15. GE Healthcare's Clinical Systems division maintains offices in Madison, Wisconsin as well as maintaining offices elsewhere in Wisconsin. In addition, a repair site for

ultrasound technology serviced by GE Healthcare's Clinical Systems division is located in this District in Madison, Wisconsin.

16. Venue is proper in this District pursuant to 28 U.S.C. §§ 1391(b) and 1391(c) and/or 28 U.S.C. § 1400(b).

FACTS GIVING RISE TO THIS ACTION

17. Paragraphs 1 - 16 are incorporated by reference as if set forth here in full.

18. GE is one of the world's largest providers of ultrasound equipment and technology.

19. Sonosite makes, uses, sells, and/or offers for sale ultrasound systems in competition with GE.

20. On information and belief, Sonosite has made, used, sold and/or offered for sale products and/or services covered by one or more claims of the GE Patents-In-Suit, including (but not limited to) Sonosite's MicroMaxx™ Ultrasound System, Titan™ Ultrasound System, M-Turbo™ Ultrasound System, and S-Series Ultrasound Systems.

21. In addition, on information and belief, Sonosite has induced others to infringe one or more claims of the GE Patents-In-Suit through the sales of product and/or services such as Sonosite's MicroMaxx™ Ultrasound System, Titan™ Ultrasound System, M-Turbo™ Ultrasound System, and S-Series Ultrasound Systems.

22. Further, on information and belief, Sonosite has contributorily infringed one or more claims of the GE Patents-In-Suit through the sales of product and/or services such as Sonosite's MicroMaxx™ Ultrasound System, Titan™ Ultrasound System, M-Turbo™ Ultrasound System, and S-Series Ultrasound Systems.

23. GE therefore seeks damages and a permanent injunction against Sonosite's manufacture, use, sale and/or offer for sale of the MicroMaxx™, Titan™, M-Turbo, and S-Series Ultrasound systems and other Sonosite systems that infringe the GE Patents-In-Suit.

FIRST CAUSE OF ACTION

Infringement Of The '415 Patent

24. Paragraphs 1 - 23 are incorporated by reference as if set forth here in full.

25. U.S. Patent No. 4,932,415 ("the '415 patent"), which is entitled "Method Of Color Coding Two Dimensional Ultrasonic Doppler Velocity Images of Blood Flow On A Display," issued on June 12, 1990. The named inventors are Bjorn A.J. Angelsen, Kjell Kristoffersen, and Hans G. Torp. The assignee of the '415 patent is GE Medical Systems (Norway) AS. A copy of the '415 patent is attached as Exhibit A hereto.

26. On information and belief, Sonosite's manufacture, use, sale, and/or offer for sale of the MicroMaxx™ Ultrasound System, Titan™ Ultrasound System, M-Turbo™ Ultrasound System, and S-Series Ultrasound Systems constitutes infringement of the '415 patent, either directly, indirectly, literally or under the doctrine of equivalents.

27. Sonosite's activities violate one or more subsections of 35 U.S.C. § 271.

28. On information and belief, Sonosite's infringement of the '415 patent has been willful and deliberate.

29. If Sonosite's infringing activities are not enjoined, GE will suffer irreparable harm that cannot be adequately compensated by a monetary award.

30. GE has suffered economic harm as a result of Sonosite's infringing activities in an amount to be proven at trial.

SECOND CAUSE OF ACTION

Infringement Of The '294 Patent

31. Paragraphs 1 - 30 are incorporated by reference as if set forth here in full.

32. U.S. Patent 5,584,294 (the "'294 patent"), which is entitled "Method And Apparatus For Ultrasonic Blood Flow Display," issued on December 17, 1996. The named inventors are Shinichi Amemiya, Taiho Ri, and Takaio Jibiki. GE Yokogawa Medical Systems, Ltd. is the assignee of the '294 patent. GE Medical Systems Global Technology Company LLC

is a licensee under the '294 patent with the sole right to enforce the '294 patent. A copy of the '294 patent is attached as Exhibit B hereto.

33. On information and belief, Sonosite's manufacture, use, sale, and/or offer for sale of the MicroMaxx™ Ultrasound System, Titan™ Ultrasound System, M-Turbo™ Ultrasound System, and S-Series Ultrasound Systems constitutes infringement of the '294 patent, either directly, indirectly, literally or under the doctrine of equivalents.

34. Sonosite's activities violate one or more subsections of 35 U.S.C. § 271.

35. On information and belief, Sonosite's infringement of the '294 patent has been willful and deliberate.

36. If Sonosite's infringing activities are not enjoined, GE will suffer irreparable harm that cannot be adequately compensated by a monetary award.

37. GE has suffered economic harm as a result of Sonosite's infringing activities in an amount to be proven at trial.

THIRD CAUSE OF ACTION

Infringement Of The '447 Patent

38. Paragraphs 1 - 37 are incorporated by reference as if set forth here in full.

39. U.S. Patent No. 6,120,447 (the "'447 patent"), which is entitled "Ultrasound Image Data Wireless Transmission Techniques," issued on September 19, 2000. The named inventor is Paul Mullen. The '415 patent is assigned to General Electric Company. A copy of the '447 patent is attached as Exhibit C hereto.

40. On information and belief, Sonosite's manufacture, use, sale, and/or offer for sale of the MicroMaxx™ Ultrasound System and the M-Turbo™ Ultrasound System constitutes infringement of the '447 patent, either directly, indirectly, literally or under the doctrine of equivalents.

41. Sonosite's activities violate one or more subsections of 35 U.S.C. § 271.

42. On information and belief, Sonosite's infringement of the '447 patent has been willful and deliberate.

43. If Sonosite's infringing activities are not enjoined, GE will suffer irreparable harm that cannot be adequately compensated by a monetary award.

44. GE has suffered economic harm as a result of Sonosite's infringing activities in an amount to be proven at trial.

FOURTH CAUSE OF ACTION

Infringement Of The '327 Patent

45. Paragraphs 1 - 44 are incorporated by reference as if set forth here in full.

46. U.S. Patent No. 6,210,327 (the "'327 patent"), which is entitled "Method And Apparatus For Sending Ultrasound Image Data To Remotely Located Device," issued on April 3, 2001. The named inventors are Charles C. Brackett, Gregory C. Stratton, James S. Lehouillier, Jeannette M. Eichholz, and Takao Shiibashi. The '327 patent is assigned to General Electric Company. A copy of the '327 patent is attached as Exhibit D hereto.

47. On information and belief, Sonosite's manufacture, use, sale, and/or offer for sale of the MicroMaxx™ Ultrasound System, M-Turbo™ Ultrasound System, and S-Series Ultrasound Systems constitutes infringement of the '327 patent, either directly, indirectly, literally or under the doctrine of equivalents.

48. Sonosite's activities violate one or more subsections of 35 U.S.C. § 271.

49. On information and belief, Sonosite's infringement of the '327 patent has been willful and deliberate.

50. If Sonosite's infringing activities are not enjoined, GE will suffer irreparable harm that cannot be adequately compensated by a monetary award.

51. GE has suffered economic harm as a result of Sonosite's infringing activities in an amount to be proven at trial.

FIFTH CAUSE OF ACTION

Infringement Of The '225 Patent

52. Paragraphs 1 - 51 are incorporated by reference as if set forth here in full.

53. U.S. Patent No. 6,418,225 (the "'225 patent"), which is entitled "Method And Apparatus For Feature Configuration In Remotely Located Ultrasound Imaging System," issued on July 9, 2002. The named inventors are Gregory C. Stratton, Charles Cameron Brackett, and Chandler A. Johnson. The '225 patent is assigned to General Electric Company. A copy of the '225 patent is attached as Exhibit E hereto.

54. On information and belief, Sonosite's manufacture, use, sale, and/or offer for sale of the MicroMaxx™ Ultrasound System and M-Turbo™ Ultrasound System constitutes infringement of the '225 patent, either directly, indirectly, literally or under the doctrine of equivalents.

55. Sonosite's activities violate one or more subsections of 35 U.S.C. § 271.

56. On information and belief, Sonosite's infringement of the '225 patent has been willful and deliberate.

57. If Sonosite's infringing activities are not enjoined, GE will suffer irreparable harm that cannot be adequately compensated by a monetary award.

58. GE has suffered economic harm as a result of Sonosite's infringing activities in an amount to be proven at trial.

SIXTH CAUSE OF ACTION

Infringement Of The '859 Patent

59. Paragraphs 1 - 58 are incorporated by reference as if set forth here in full.

60. U.S. Patent No. 6,102,859 ("the '859 patent"), which is entitled "Method And Apparatus For Automatic Time And/Or Lateral Gain Compensation In B-Mode Ultrasound Imaging," issued on August 15, 2000. The named inventor is Larry Y. L. Mo. The assignee of

the ‘859 patent is General Electric Company. A copy of the ‘859 patent is attached as Exhibit F hereto.

61. On information and belief, Sonosite’s manufacture, use, sale, and/or offer for sale of the MicroMaxx™ Ultrasound System, Titan™ Ultrasound System, M-Turbo™ Ultrasound System, and S-Series Ultrasound Systems constitutes infringement of the ‘859 patent, either directly, indirectly, literally or under the doctrine of equivalents.

62. Sonosite’s activities violate one or more subsections of 35 U.S.C. § 271.

63. On information and belief, Sonosite’s infringement of the ‘859 patent has been willful and deliberate.

64. If Sonosite’s infringing activities are not enjoined, GE will suffer irreparable harm that cannot be adequately compensated by a monetary award.

65. GE has suffered economic harm as a result of Sonosite’s infringing activities in an amount to be proven at trial.

PRAYER FOR RELIEF

WHEREFORE, GE seeks the following relief from this Court:

(a) That this Court adjudge and decree that Sonosite has, directly and indirectly, infringed one or more of the GE Patents-In-Suit and that each of the GE Patents-In-Suit is valid and enforceable;

(b) A permanent injunction enjoining Sonosite and its affiliates, subsidiaries, officers, directors, employees, agents, representatives, licensees, successors, assigns, and all those acting for Sonosite and on its behalf, or acting in concert with it directly or indirectly, from importing, making, using, selling, and/or offering to sell: (1) the MicroMaxx™ Ultrasound System, (2) the Titan™ Ultrasound System, (3) the M-Turbo™ Ultrasound System, (4) the S-Series Ultrasound Systems; and/or (5) any other Sonosite ultrasound system that would infringe any of the GE Patent-In-Suit;

(c) An award of damages, together with interest, to GE in an amount adequate to compensate GE for Sonosite's infringement of the GE Patents-In-Suit, as provided in 35 U.S.C. § 284;

(d) An adjudication that Sonosite has willfully infringed the GE Patents-In-Suit and increasing the award of damage to GE up to three times in view of Sonosite's willful infringement;

(e) A declaration that this is an exceptional case under 35 U.S.C. § 285 and that GE be awarded its attorneys' fees and costs incurred in prosecuting their claims as provided under 35 U.S.C. § 285; and

(f) Such other relief as this Court deems proper.

DEMAND FOR JURY TRIAL

Pursuant to Rule 38 of the Federal Rules of Civil Procedure, GE hereby demands trial by jury in this action of all issues triable by jury.

Dated: November 16, 2007

Respectfully submitted,

s/Allen A. Arntsen
Allen A. Arntsen
FOLEY & LARDNER LLP
150 East Gilman Street
Verex Plaza
Madison, WI 53703
Tel: (608) 257-5035
Fax: (608) 258-4258

Robert F. Ruyak
Matthew M. Wolf
Cono A. Carrano
Marc A. Cohn
John E. Nilsson
HOWREY LLP
1299 Pennsylvania Avenue, N.W.
Washington, D.C. 20004
Tel: (202) 783-0800
Fax: (202) 383-6610

Jennifer A. Sklenar
HOWREY LLP
550 South Hope Street
Suite 1100
Los Angeles, CA 90071
Tel: (213) 892-1800
Fax: (213) 892-2100

Attorneys for Plaintiffs

EXHIBIT A

United States Patent [19]

Angelsen et al.

[11] **Patent Number: 4,932,415**

[45] **Date of Patent: Jun. 12, 1990**

[54] **METHOD OF COLOR CODING TWO DIMENSIONAL ULLTRASONIC DOPPLER VELOCITY IMAGES OF BLOOD FLOW ON A DISPLAY**

[75] Inventors: **Bjørn A. J. Angelsen**, Trondheim; **Kjell Kristoffersen**, Oslo; **Hans G. Torp**, Trondheim, all of Norway

[73] Assignee: **Vingmed Sound A/S**, Horten, Norway

[21] Appl. No.: **270,088**

[22] Filed: **Nov. 14, 1988**

[51] **Int. Cl.**[5] **A61B 8/00**

[52] **U.S. Cl.** **128/661.09**

[58] **Field of Search** 128/661.08, 661.09, 128/661.10; 73/861.25; 358/81–82; 342/181

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,612,937	9/1986	Miller	128/661.09 X
4,641,668	2/1987	Namekawa	128/661.09
4,719,923	1/1988	Hartwell et al.	128/661.08
4,768,515	9/1988	Namekawa	128/661.09
4,785,402	11/1988	Matsuo et al.	128/661.08 X

Primary Examiner—Francis Jaworski

[57] **ABSTRACT**

A pulsed ultrasonic beam is swept over an image field and the backscattered signal is sampled for a multiplicity of timelags to obtain signals from a multiplicity of depths along the beam, the signals forming a two-dimensional set of range cells. A combination of the bandwidth and power of the signal from each range cell is utilized to identify those regions of the image field at which the blood velocity is sufficiently high that Doppler frequency aliasing occurs. These regions are then designated with a single color with strong contrast to the colors employed in the regions wherein the blood velocity is below this limit, so that the regions of high velocity flow are clearly delineated in the image. Where the velocity is sufficiently low that no frequency aliasing occurs, the mean Doppler shift is coded into a continuous distribution of colors for indicating the magnitude of the imaged velocities.

6 Claims, 6 Drawing Sheets

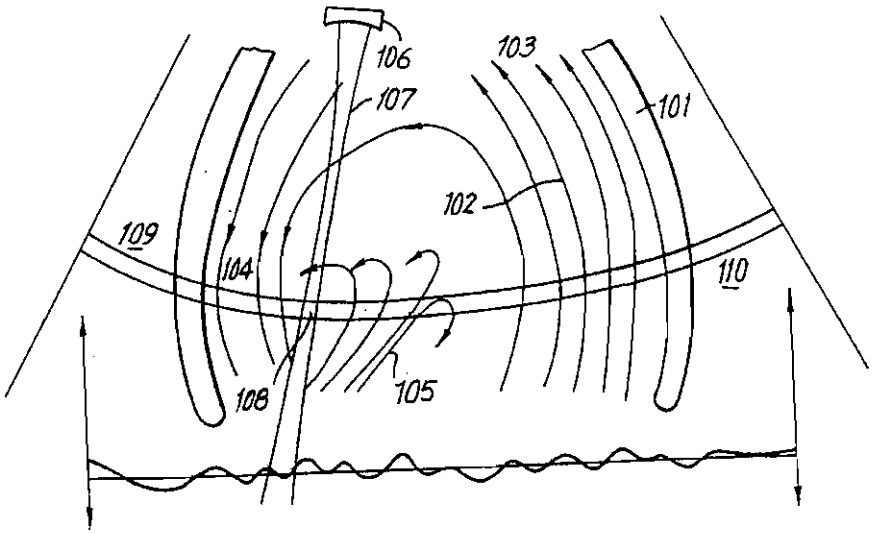


FIG. Ia

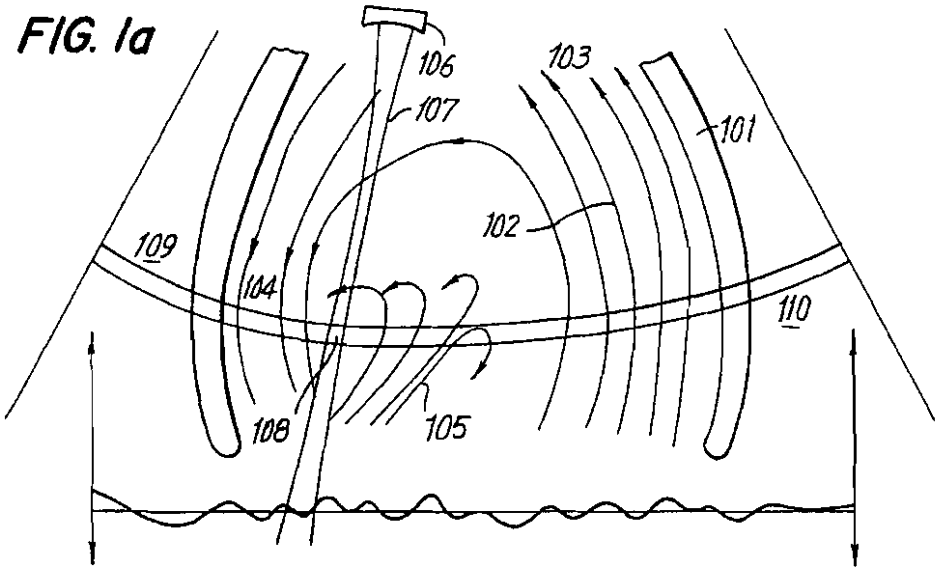


FIG. Ib

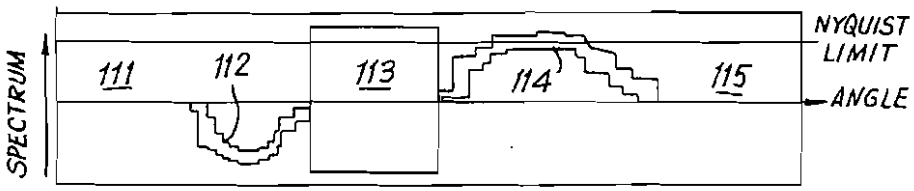


FIG. Ic

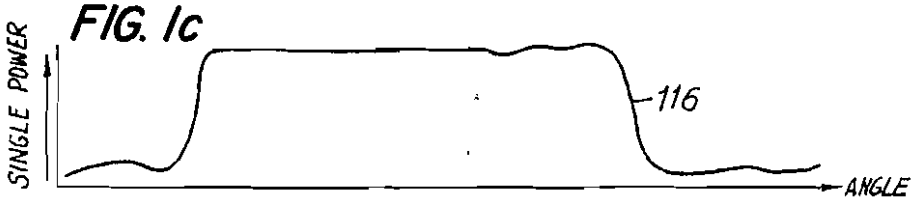
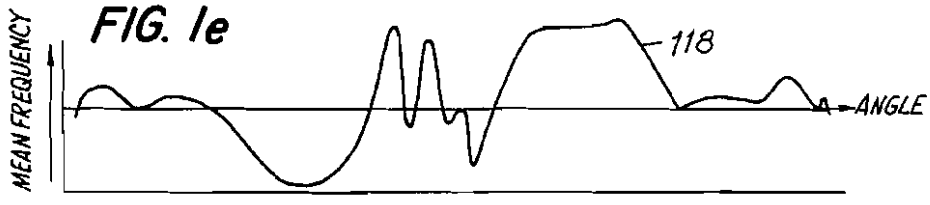


FIG. Id

FIG. Ie



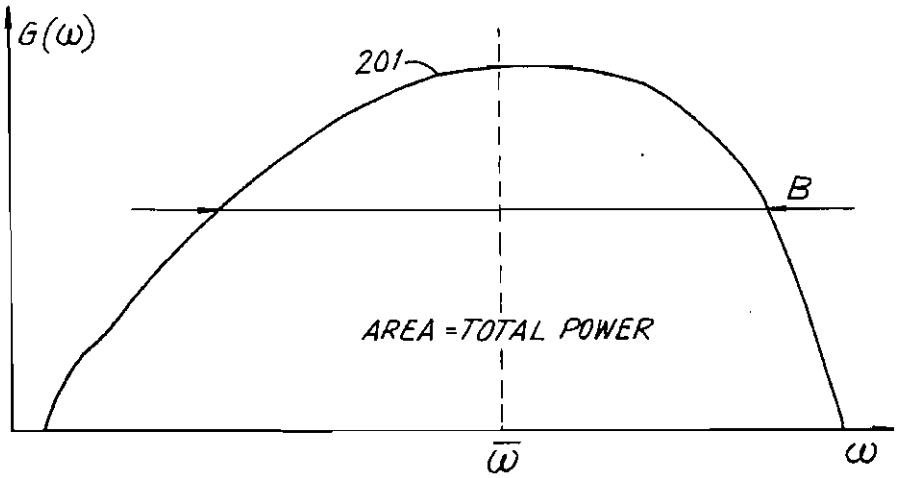
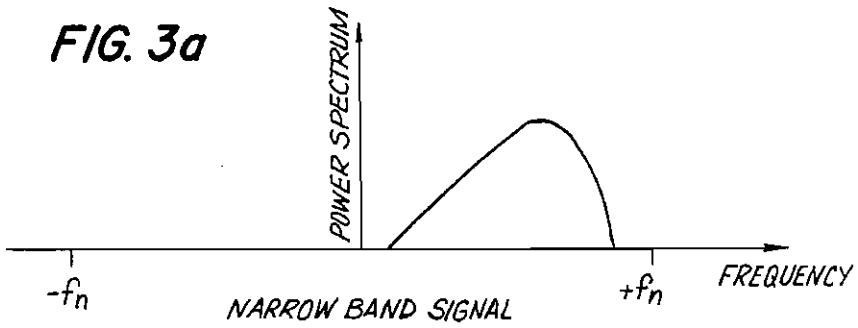


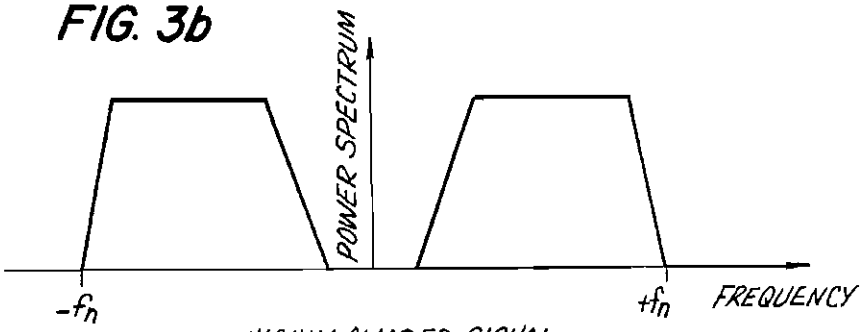
FIG. 2

FIG. 3a



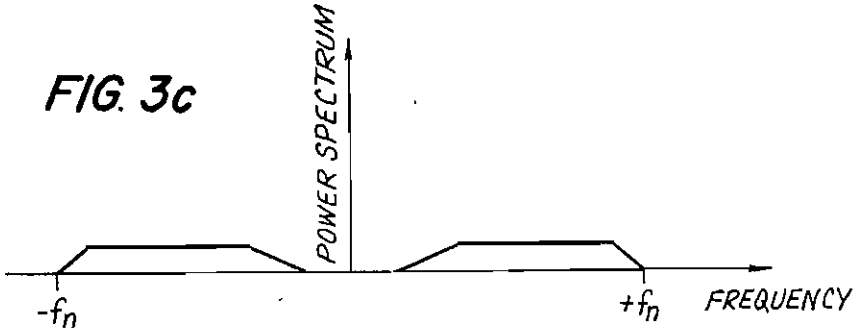
NARROW BAND SIGNAL

FIG. 3b



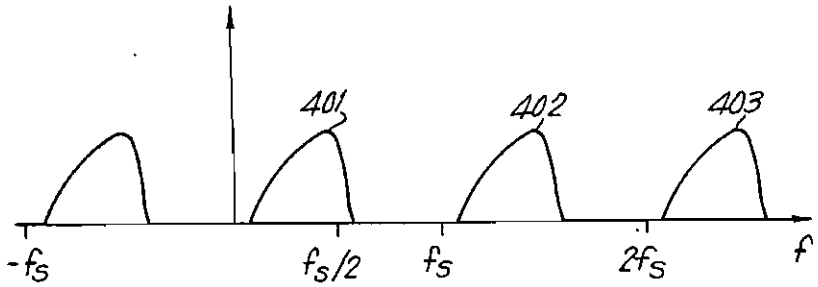
HIGHLY ALIASED SIGNAL

FIG. 3c



NOISE

FIG. 4a



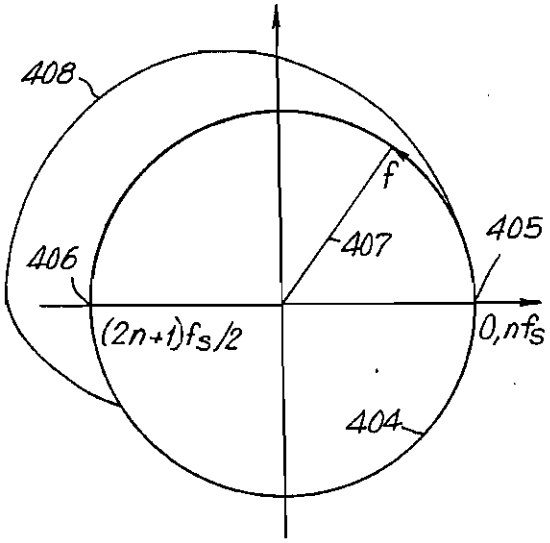


FIG. 4b

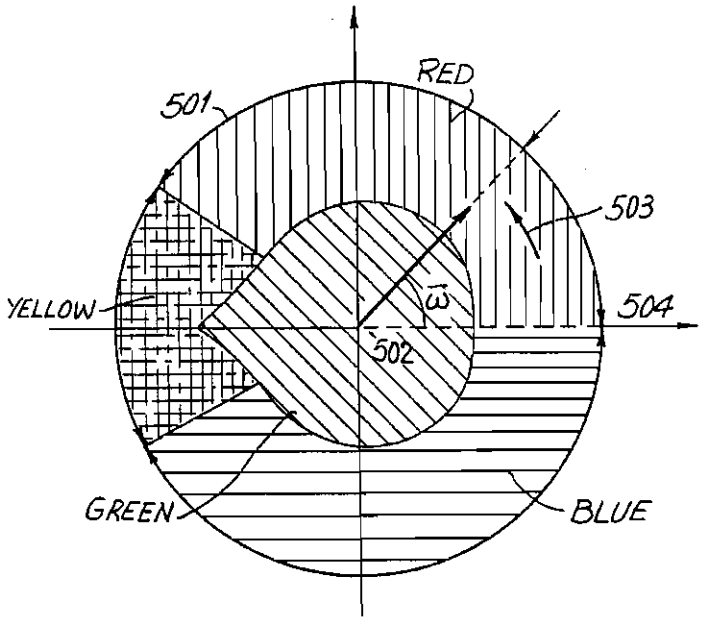

RED
501
503
YELLOW
$\vec{\omega}$
504
502
GREEN
BLUE

FIG. 5a

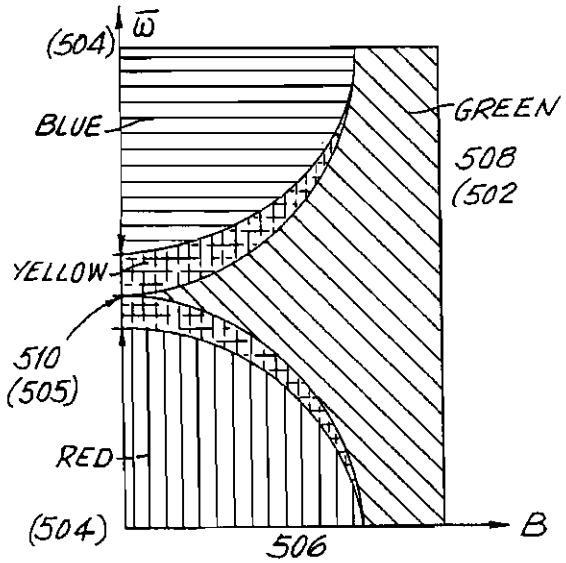
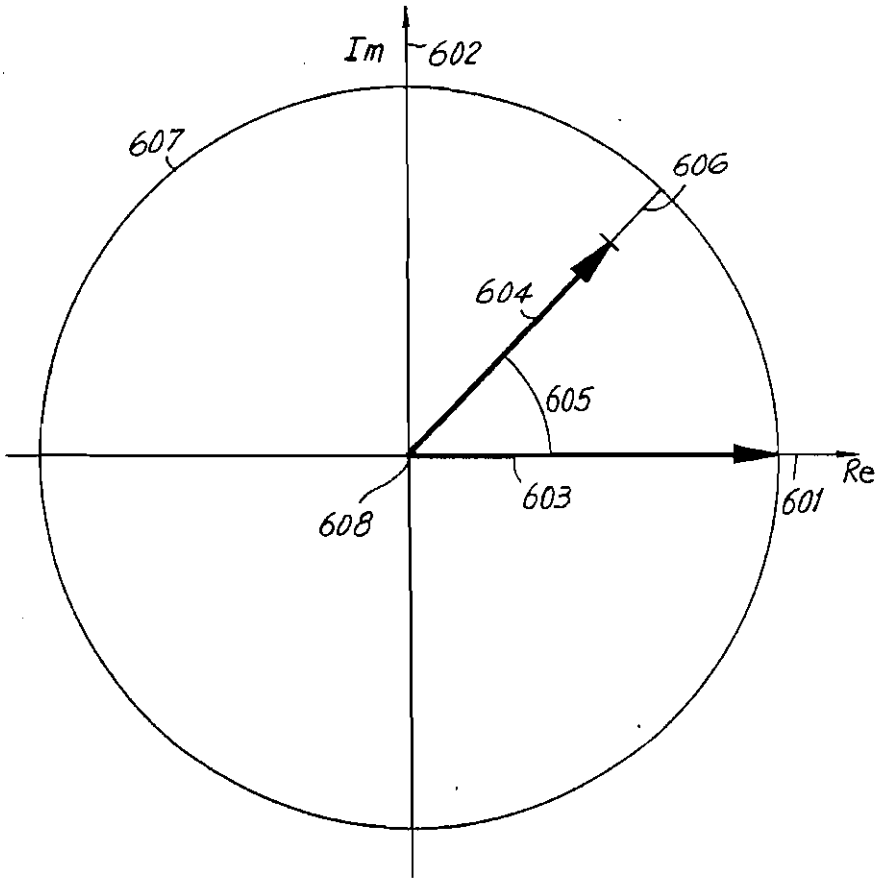

$\vec{\omega}$
(504)
BLUE
GREEN
508
(502
YELLOW
510
(505)
RED
(504)
506
B

FIG. 5b

FIG. 6



METHOD OF COLOR CODING TWO DIMENSIONAL ULLTRASONIC DOPPLER VELOCITY IMAGES OF BLOOD FLOW ON A DISPLAY

FIELD OF THE INVENTION

The present invention relates to the display of two-dimensional ultrasonic Doppler velocity images of blood or other fluid flow and, more particularly, to the color-coding of such information in a manner which provides the viewer with accurate and readily understandable differentiation of the various conditions and combinations of flow.

BACKGROUND OF THE INVENTION

There exist in the marketplace apparatus for presenting a color-coded two-dimensional image of a blood velocity field using noninvasive ultrasonic blood velocity measurements based on the Doppler effect. Broadly, the images are obtained by sweeping a pulsed ultrasound beam along a plane, sampling the hackscattered signal for a multitude of depths and, on the basis of the Doppler shift in frequency for each such depth, estimating for each beam direction the blood velocities as a function of depth along the beam. Thus, as the beam is operatively swept across the field, a two-dimensional image of blood velocities is generated.

A first experimental instrument for two-dimensional flow imaging was presented by W. Bommer and L. Miller in 1982 ("Real Time Two Dimensional Color-Flow Doppler: Enhanced Doppler Flow Imaging in the Diagnosis of Cardiovascular Disease", 49 Am. J. Cardiology 943), and the first commercial device was developed by the Aloka Company, Ltd. of Japan (Kasai et al, "Real-Time Two-Dimensional Blood Flow Imaging Using an Autocorrelation Technique", IEEE Trans. Son. Ultras., Vol. SU-32, No. 3, May 1985, pp. 458–63). Several companies have since disclosed similar instruments such, for example, as is described in U.S. Pat. No. 4,612,937 (Miller) and German Offenlegnngsschrift DE 36 37 056 Al.

The basic principles of the methodology of these prior art imaging techniques present practical limitations in the ability to represent true velocities and, in particular, to effectively distinguish betweeen laminar flow, on the one hand, and turbulent or very high velocity flows, on the other. These limitations result from inherent aspects of the methodology in that:

1. With Doppler techniques only those velocity components along the beam direction are measured; and
2. Since the beam must be pulsed to obtain spatial resolution along the beam, at high frequencies there is frequency aliasing when the Doppler shift exceeds the Nyquist limit of the sampling theorem, thus limiting the maximum flow velocity capable of measurement with this technique.

With particular respect to the latter point, if we assume that the pulse repetition frequency for the pulsed beam is f_s, then the Nyquist sampling theorem generally states that Doppler frequencies f_d which satisfy the requirement

$$|f_d| < f_s/2$$

can be measured without ambiguity. Using the complex envelope of the Doppler signal for frequency analysis,

this requirement can be modified to the effect that Doppler frequencies in the range

$$f_s - D < f_d < f_s + D$$

can be analyzed without ambiguity. D is an arbitrary number less than f_s which can be selected as appropriate so that the interval covers the set of frequencies of interest.

The prior art imaging techniques and apparatus fail to display combinations of laminar and very high velocity or turbulent flow in a manner which satisfactorily enables a viewer to readily and accurately identify the true dynamics of the complex flows being imaged.

SUMMARY OF THE INVENTION

The present invention discloses a method of color-coding the information obtained by the Doppler shift-based measurements and for presenting the color-coded data s that all available information is displayed in the image with good color contrast between the different kinds of flow information derived from the Doppler measurements. A particularly advantageous aspect of the present invention lies in the manner in which the two-dimensional Doppler information is coded onto the screen to form a representational image of the flow velocity field. In accordance with the present invention the Doppler information is displayed using a color-coding scheme wherein laminar flow is depicted by a continuous range of colors, while turbulence or very high velocity flow is represented by a single, contrasting color so as to clearly and readily indicate to an observer those areas in which turbulent or very high velocity flow is present, and thereby enable the viewer to quickly and clearly differentiate those areas from areas of laminar flow and recognize the interrelationships between those areas.

The method of the invention employs a combination of the measured bandwidth and power of the backscattered Doppler signal to accurately determine those regions in the image at which the blood velocity is so high that Doppler frequency aliasing, yielding ambiguous velocity data, occurs. These regions are then designated in the image by a single color which strongly contrasts with the colors employed in those regions where the blood velocity is below that at which Doppler frequency aliasing occurs. In this manner, the regions of very high velocity or turbulent flow are clearly delineated in the colorcoded image.

Similarly, the measured bandwidth and the power of the backscattered Doppler signal are used to determine those regions in the image where laminar flow with no aliasing in the Doppler frequency occurs. In this case an approximate mean frequency of the Doppler signal is used as input to a continuous color scale which depicts the velocities in the laminar flow.

Other objects and features of the present invention will become apparent from the following detailed description considered in conjuntion with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for purposes of illustration and not as a definition of the limits of the invention, for which reference shonld be made to the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, wherein similar reference characters denote similar elements throughout the several views:

FIG. 1 schematically and diagramatically illustrates various aspects of the generation of blood flow velocity information in accordance with the invention; specifically, FIG. 1*a* schematically depicts complex blood flow in an area being ultrasonically scanned, and FIG. 1*b* graphically depicts the corresponding Fourier spectrum, FIG. 1*c* graphically indicates the backscattered signal power, FIG. 1*d* graphically depicts the bandwidth, and FIG. 1*e* graphically illnstrates the mean power of the blood in a single scanned range cell;

FIG. 2 graphically depicts the definition of spectra bandwidth, mean frequency, and total power based on the spectral density for a fixed time period;

FIGS. 3*a*, 3*b* and 3*c* graphically depict examples of power spectra for normal laminar flow with no aliasing, for highly aliased flow, and for no signal (i.e. noise only), respectively;

FIGS. 4*a* and 4*b* graphically illustrate the periodicity introduced in the signal spectrum from pulsing of the ultrasonic beam, and a representation of such periodicity wherein the frequency scale is folded about a circle, respectively;

FIGS. 5*a* and 5*b* illustrate, in two alternate forms, use of the mean frequency, the bandwidth, and the power of the Doppler signal for generating a color scale in accordance with the invention; and

FIG. 6 depicts the manner in which estimates of the mean frequency, the bandwidth, and the power of the backscattered signal from a single range cell may be obtained from the autocorrelation function of the complex envelope of the Doppler signal for zero and unity lag.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With particular reference to the drawings, FIG. 1 schematically depicts the application of the principle by which a color-coded image of the blood velocities in a human heart is generated. More particularly, there illustrated by way of example is a schematic representation of blood flow in a cross-section of the left heart ventricle **101** during diastole. Streamlines indicate the inflow **102** from the left atrium to the left ventricle, changing direction at the apex **103** of the left ventricle and flowing into the left ventricular outflow tract **104**. Also indicated by streamlines in FIG. 1*a* is a jet flow **105** from a leaking aortic valve, a heart failure which is advantageously detectable in accordance with the method of the invention through strong contrast imaging with respect to the normal laminar flow of blood.

An ultrasonic transducer **106** emits a pulsed ultrasonic beam **107** into the heart. The beam can be swept over the image field either, for example, electronically using any of various known arrays, or mechanically by physically moving the transducer, all utilizing well known methods and apparatus. For ease of description and understanding, the drawings depict the situation of continuous movement of the transducer by which a continuous sectorial sweep of the ultrasonic beam is obtained. The following explanation is with respect to the signal from a single range cell **108** as the beam is swept over the image field.

Starting from the left in FIG. 1*a*, the range cell first passes through a region **109** of no blood flow, then enters the area **104** of laminar flow away from the transducer, next enters the region of jet flow **105**, then enters the region of laminar inflow **102** (i.e. into the left ventricle from the left atrium) and, finally, leaves the left ventricle entering a region **110** of no blood flow. As should be apparent, since the ultrasonic beam is swept across the image over time, there is a direct correspondence between time and the angular direction of the ultrasonic beam.

Depicted below the heart in FIG. 1*a* is spectral analysis (FIG 1*b*) of the Doppler signal from the range cell a the transducer is scanned across the image field. Time and corresponding angular direction appear along the horizontal axis, Doppler frequency along the vertical axis, and the greyscale of the display indicates the spectral intensity of the signal. The first or leftmost portion **111** represents the spectrum of noise from the transducer and the preamplifiers of the receivers. This noise has a wide bandwidth with fairly low spectral intensity. As the range cell then enters the region **104** of laminar flow in the outflow tract, a typical narrowband spectrum **112** of high spectral intensity is obtained from the blood, overlaid on the background noise spectrum which has the same spectral intensity as at **111**. As the range cell next passes into the jet flow **105** from the leaking aortic valve, the spectrum takes on the typical shape **113** of a high degree of aliasing— namely, substantially equal spectral intensity over all frequencies providing a wide bandwidth, similar to that resulting from the noise at position **111** except that the spectral intensity at the jet flow **105** is significantly higher. After this the range cell enters the region **102** of laminar inflow to the left ventricle, yielding a narrow band spectrum **114** with negative Doppler frequencies, again overlaying the basic background noise spectrum. Finally, the range cell leaves the region of flow and spectral analysis reveals noise spectrum **115** substantially identical to that seen at **111**.

As should now be apparent, the spectral graph of FIG. 1*b* incorporates regions of three basic types:

1. Laminar flow of sufficiently low velocities that aliasing does not occur. The spectrum (**112, 114**) is narrowband with a spectral intensity higher than that of the background noise, and the mean Doppler frequency provides an approximation or estimate of blood velocity.
2. High flow velocities which result in a large degree of aliasing. The wideband spectrum (**113**) is similar to that for background noise, but the spectral power is higher than for noise alone. The blood velocities cannot be determined due to the aliasing, and the mean Doppler frequency does not provide meaningful information about blood velocity.
3. No signal from blood only noise. This results in a wideband spectrum (**111, 115**) with lowest power, and the mean frequency does not provide meaningful information about blood velocity.

These three situations can accordingly be distinguished from one another on the basis of certain characteristics of the spectrum—namely, its power and the bandwidth:

1. Laminar flow of sufficiently low velocities that aliasing does not occur: Power high and spectral bandwidth low; mean frequency used to indicate velocity.
2. High flow velocities which result in a large degree of aliasing: Power and spectral bandwidth both high.
3. No signal from the blood, only noise: Power low and spectral bandwidth high.

FIG. 1 also depicts the total signal power **116** (FIG. 1*c*), the spectral bandwidth **117** (FIG. 1*d*), and the mean frequency **118** (FIG. 1*e*) of the backscattered signal from the blood and noise. The additional figures clearly

indicate the manner in which the different situations or combinations of flow can be distinguished by these spectral parameters.

A graphic definition of the spectral mean frequency, bandwidth and signal power is shown in FIG. 2. A schematic short spectrum, $G(\omega)$, is represented by the curve 201 with angular frequency along the horizontal axis and spectral intensity along the vertical axis. The angular mean frequency $\bar{\omega}$ indicates the middle of the spectrum $G(\omega)$ and can be mathematically defined as the first moment or point of gravity of the spectrum:

$$\bar{\omega} = \frac{\int d\omega \omega G(\omega)}{\int d\omega G(\omega)}$$

where the integration is taken over the entire frequency axis. As above-described with respect to FIG. 1, the mean frequency is of interest only with the narrowband spectra of laminar flow, wherein the mean frequency represents blood velocity in the range cell. It is not, therefore, critical to have the exact first moment of the spectrum; the mode or maximum value of the spectrum, or other definitions that indicate the central portion of the spectrum, may instead be employed.

The bandwidth B indicates the width of the spectrum, as shown in FIG. 2, and may for example be defined through the second moment of the spectrum:

$$B^2 = \frac{\int d\omega(\omega - \bar{\omega})^2 G(\omega)}{\int d\omega G(\omega)}$$

where, once again, the integration is taken over the entire frequency axis. As in the case of mean frequency, this precise definition of the bandwidth is not of special interest; our interest, rather, is in providing a parameter which gives an indication of spectral width.

The total power of the signal is the area under the spectral curve of FIG. 2. The spectral intensity at any particular frequency is the height of the spectral curve at this frequency, this spectral intensity being displayed as the grey scale of the spectrum in FIG. 1*b*. Examples of the spectral power or intensity at a defined time for the three situations discussed above are illustrated in FIG. 3*a* which depicts laminar flow without aliasing, in FIG. 3*b* which depicts highly aliased flow, and in FIG. 3*c* which depicts the spectral power distribution of noise alone without any signal components.

The pulsing of the ultrasonic beam introduces a periodicity of the spectrum that is seen in FIG. 4*a*. The figure depicts a typical spectrum 401 from laminar flow, the spectrum being repeated at multiples of the pulse repetition frequency (PRF) f_s, as seen at 402 and 403. FIG. 4*b* depicts an alternate way of illustrating this periodicity in which the entire frequency axis is wrapped about a circle 404. In FIG. 4*b*, zero and multiples of f_s, nf_s lie at the intersection point 405 of the circle 404 and the right horizontal axis, whereas the intersection point 406 of the circle and the left horizontal axis corresponds to odd multiples of $f_s/2$, $(2n+1)f_s/2$.

With particular reference to the representation of FIG. 4*b*, starting from zero frequency at 405 and positively increasing the Doppler frequency—i.e. moving counterclockwise along the circle 404—and passing the Nyquist frequency $f_s/2$ at 406 we enter the lower half of the circle and, continuing to increase the frequency, pass the starting point 405. If, on the other hand, we start from zero at 405 with a negatively increasing Doppler frequency we move clockwise along the circle, first passing the Nyquist frequency $-f_s/2$ at 406 and, with negatively increasing Doppler shift, pass $-f_s$ at 405 and so on. For a particular frequency such, for example, as is indicated at 407 in FIG. 4*b*, we do not know how many times we have moved around the circle, thus introducing an ambiguity that corresponds to the periodicity of the spectrum illustrated in FIG. 4*a* and is a well known prediction of the Nyquist sampling theorem. The spectrum can then be shown as the curve 408 in this representation.

Thus, if we know that the frequency is increasing in the positive sense, then we have an unambiguous region from 0 to f_s. Similarly, if we know that the frequency is increasing in the negative sense, the unambiguous region extends from 0 to $-f_s$.

As should now be apparent, a pulsed color flow mapper can, in accordance with the invention, readily differentiate between three basic conditions or situations of blood flow—namely: (1) laminar flow without aliasing, producing a narrowband spectrum; (2) wideband Doppler signals coming either from aliasing because of high velocities or from turbulent flow with small eddies that produce both positive and negative velocities within the same range cell; and (3) noise only with no signal from the blood. These three situations can be differentiated using the bandwidth and the power of the Doppler signal and, in the case of laminar flow without aliasing, the mean Doppler frequency will provide an indication of blood velocity in the range cell. Thus, the present invention presents a method for coding the Doppler information onto a display screen so that the different conditions or situations of blood flow are displayed with strong contrast and minimal ambiguity.

In accordance with the invention, therefore, the Doppler information from the backscattered ultrasonic probe signal is treated, for the purposes of color-coded representational imaging thereof, as follows:

1. For laminar flow with a narrow bandwidth signal, the mean Doppler shift is coded in a continuous variation of colors from zero Doppler frequency past the Nyquist frequency toward the PRF of the instrument. Since there is generally a continuous spatial change in velocities, the coding advantageously enables the viewer to follow the continuous change in colors and thereby determine whether a certain color represents a frequency that has passed the Nyquist frequency in either the positive or negative direction, or its true direction is given by where it occurs relative to the Nyquist frequency. This is not, for example, the case in heretofore known color-coding schemes which present a discontinuity in the colors at the Nyquist limit making it unclear whether a color represents a positive/negative Doppler frequency above the Nyquist frequency or a negative/positive Doppler frequency below the Nyquist frequency.

2. When the blood velocity is so high that aliasing of the Doppler signal occurs, the bandwidth is high and, in accordance with the invention, a single color is employed to represent the flow. This is in contrast to currently commercially-used color scales wherein, for example, a green component proportional to the bandwidth is typically added to the existing red and blue colors producing a mosaic pattern of yellow and cyan, or of yellow and green, which does not strongly contrast with the background.

The color scale of the invention is perhaps most clearly illustrated in the color circle of FIG. 5*a*. Band-

width is on the radial axis with zero at the outer circle **501** and maximum bandwidth at the origin **502**. Mean frequency is on the angular axis **503**, as for example described with respect to FIG. **4***b*, and signal power may be represented as brightness in the colors.

A typical but nonexclusive example for low bandwidth utilizes shades of red for positively increasing frequencies starting at zero (**504**) on the circle, and shades of blue for negatively increasing frequencies starting at zero on the circle. The red and blue are then merged around the Nyquist frequency at **505** in a yellow, or purple, region which changes continuously from red on the upper halfcircle to blue on the lower halfcircle. As the bandwidth increases we move radially toward the origin, gradually substituting the color green for the red blue and yellow (or purple) so that in the area around the origin there appears only the color green. This single (green) color clearly and unambiguously indicates the critical area of high aliasing which may be of particular interest in the subject medical investigation.

The circular color scale of FIG. **5***a* may alternatively be viewed in the corresponding rectangular representation of FIG. **5***b* wherein mean frequency is on the vertical axis **507** and bandwidth is on the horizontal axis **506**. Here again, power may for example be depicted as brightness in the colors. This color scale may be thought of as cutting the circular scale of FIG. **5***a* from its zero point **504** to its origin **502** and then bending it open and shaping it to take the configuration of a rectangle. In any event, in FIG. **5***b* the low bandwidth condition is along the left vertical axis **507** and the high bandwidth condition is alon the right vertical axis **508**; thus axis **508** corresponds to the origin **502** in FIG. **5***a*, Zero mean frequency is at the bottom, increasing positively upwards, passing the Nyquist frequency **510** in the center and terminating at f_s at the top, thus corresponding to counterclockwise movement along the circular scale of FIG. **5***a*. Negative frequencies start at zero on the top of axis **508** and move downward toward $-f_s$ at the bottom, thus corresponding to clockwise movement along the circular scale. The corresponding points **502**, **504** and **505** of FIG. **5***a* are depicted in parentheses at their respective corresponding positions in FIG. **5***b*.

There are many known methods of calculating the mean frequency, bandwidth and power of the Doppler signal and, as hereinabove mentioned, only close or relative representations rather than exact calculations of these parameters are needed in accordance with the invention. Since these parameters are estimates over a limited time, they will have a random error; it may therefore be advantageous to use parameters which do not exactly represent the mean frequency, bandwidth and power, but, instead, have a smaller estimation uncertainty than parameters which provide a more exact representation thereof.

A practical and currently preferred method of estimating these three parameters is to use the autocorrelation function for the complex envelope of the Doppler signal for zero lag and for the lag between two immediately adjacent or neighboring pulses. The real and imaginary parts of the complex envelope are obtained by quadrature demodulation of the RF signal in a known manner. The autocorrelation function of the complex envelope is illustrated in the complex plane in FIG. **6** wherein **601** denotes the real axis and **602** the imaginary axis. The autocorrelation function for zero lag, R(**0**), is indicated by the arrow **603**, and the autocorrelation function with a lag of the distance between two ultrasound pulses, R(**1**), is indicated by the arrow **604**. The amplitude of R(**0**) is utilized as an estimate for the power of the signal, and the argument **605** of R(**1**) is utillized as an estimate of mean frequency. The difference **606** in amplitude of the autocorrelation function at zero lag and at unity lag forms the basis of an estimate of the signal bandwidth since the length **606** is proportional to $B^2R(0)$.

This complex representation of the autocorrelation function has a similarity to the circular color scale of FIG. **5***a* in that, for small bandwidths, the amplitude of R(**1**) is close to the amplitude of R(**0**). With small bandwidths, R(**1**) will rotate close to the circle **607** and through R(**0**), while with large bandwidths, R(**1**) will be close to the origin **608**. We can therefore let the normalized complex autocorrelation function $\rho(1)=R(1)/R(0)$ directly define the color in FIG. **5***a*, where the circle **501** now represents the unit circle in the complex plane for $\rho(1)$.

While there have been shown and described and pointed out fundamental novel features of the invention as applied to a currently preferred embodiment thereof, it will be understood that various omissions and substitutions and changes in the form and details of the disclosed method may be made by those skilled in the art without departing from the spirit of the invention. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

What is claimed is:

1. A method for color-coded imaging of blood flow velocities in a field onto a display, comprising the steps of:

scanning an ultrasonic beam pulsed at a pulse repetition frequency across the field to provide a Dopplershifted backscattered signal from a discrete set of range cells in the field;

sampling the backscattered signal from the range cells along the beam;

estimating predetermined parameters from the backscattered signal from each range cell, said parameters comprising the mean frequency, the power and the bandwidth of the backscattered signal;

assigning, on the basis of said parameters, predetermined colors for imaging the blood flow velocities on the display, such that for low bandwidth, the mean frequency is assigned to a range of selected first colors which are predeterminately varied as the mean frequency varies, in both the positive and negative sense, from zero frequency to the pulse repetition frequency of the beam, and for increasing bandwidth said first colors are gradually replaced with a single second color until, at large bandwidths, only said single second color is assigned to the display, said single second color being selected to strongly contrast with said first colors; and

mapping the assigned colors for both positive and negative mean frequencies onto the display, whereby the displayed image presents the full range of blood flow velocities in the field such that different flow conditions ma be readily distinguished.

2. A method in accordance with claim **1** wherein said color assigning step further comprises varying the brightness of said assigned first and second colors in accordance with the power of the backscattered signal.

3. A method in accordance with claim 1, wherein the mean frequency is assigned, for low bandwidth, to a continuous range of said first colors.

4. A method in accordance with claim 1, wherein said second color is green, and said first colors are red, yellow and blue, said first colors being mixed around the Nyquist frequency so as to provide in the display image a substantially continuous variation in color with corresponding variations in the mean frequency.

5. A method in accordance with claim 1, wherein said estimating step comprises estimating the autocorrelation function of the complex Doppler backscattered signal for zero lag and for the lag of the temporal distance between pulses of the ultrasonic beam.

6. A method in accordance with claim 1, wherein said second color is green, and said first colors are red, purple and blue, said first colors being mixed around the Nyquist frequency so as to provide in the display image a substantially continuous variation in color with corresponding variations in the mean frequency.

* * * * *

EXHIBIT B

US005584294A

United States Patent [19]

Amemiya et al.

[11] Patent Number: 5,584,294

[45] Date of Patent: Dec. 17, 1996

[54] METHOD AND APPARATUS FOR ULTRASONIC BLOOD FLOW DISPLAY

[75] Inventors: Shinichi Amemiya; Taiho Ri; Takao Jibiki, all of Tokyo, Japan

[73] Assignee: GE Yokogawa Medical Systems, Limited, Tokyo, Japan

[21] Appl. No.: 541,539

[22] Filed: Oct. 10, 1995

[51] Int. Cl.[6] A61B 8/00

[52] U.S. Cl. 128/660.05

[58] Field of Search 128/660.04, 660.05, 128/660.07, 661.08, 661.09, 661.10, 660.01

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Primary Examiner—George Manuel
Attorney, Agent, or Firm—Moonray Kojima

[57] ABSTRACT

In a power Doppler ultrasonic blood flow display apparatus, according to a moving signal Z representing moving of a blood flow display region, display changing means comprising changers (77, 78) and a change controller (79) displays a B-mode image also to a blood flow display region (84) while the blood flow display region (84) is moved, and displays a blood flow image when the moving of the blood flow display region (84) is stopped. Consequently the B-mode image of the target can be easily caught even while the blood flow display region is moved.

2 Claims, 5 Drawing Sheets

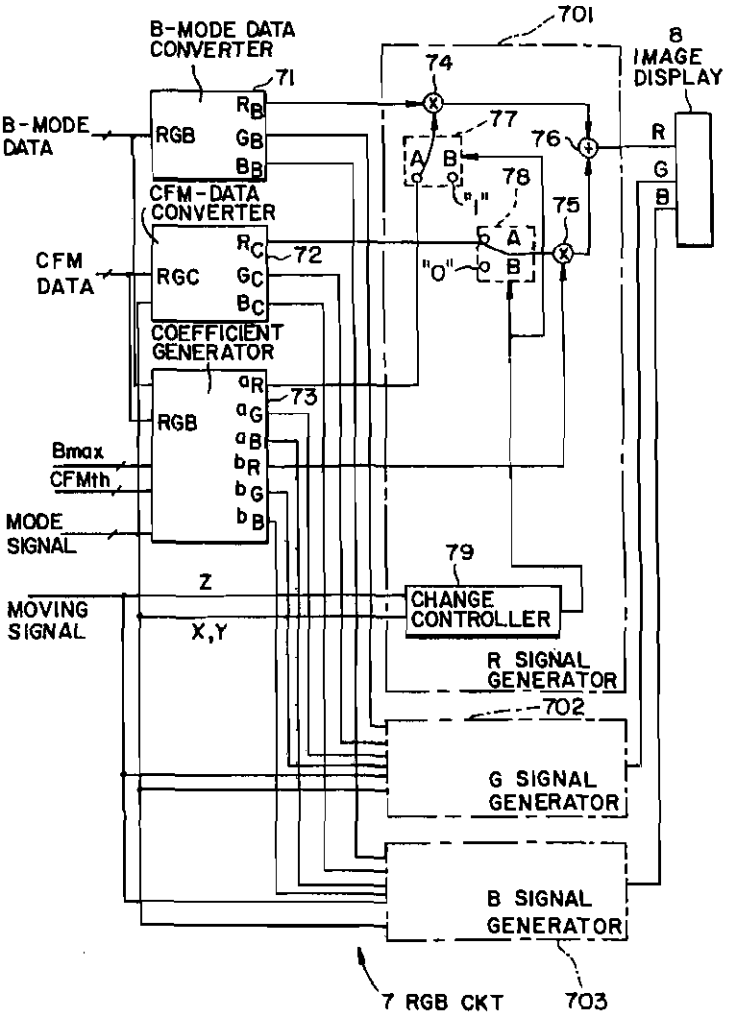
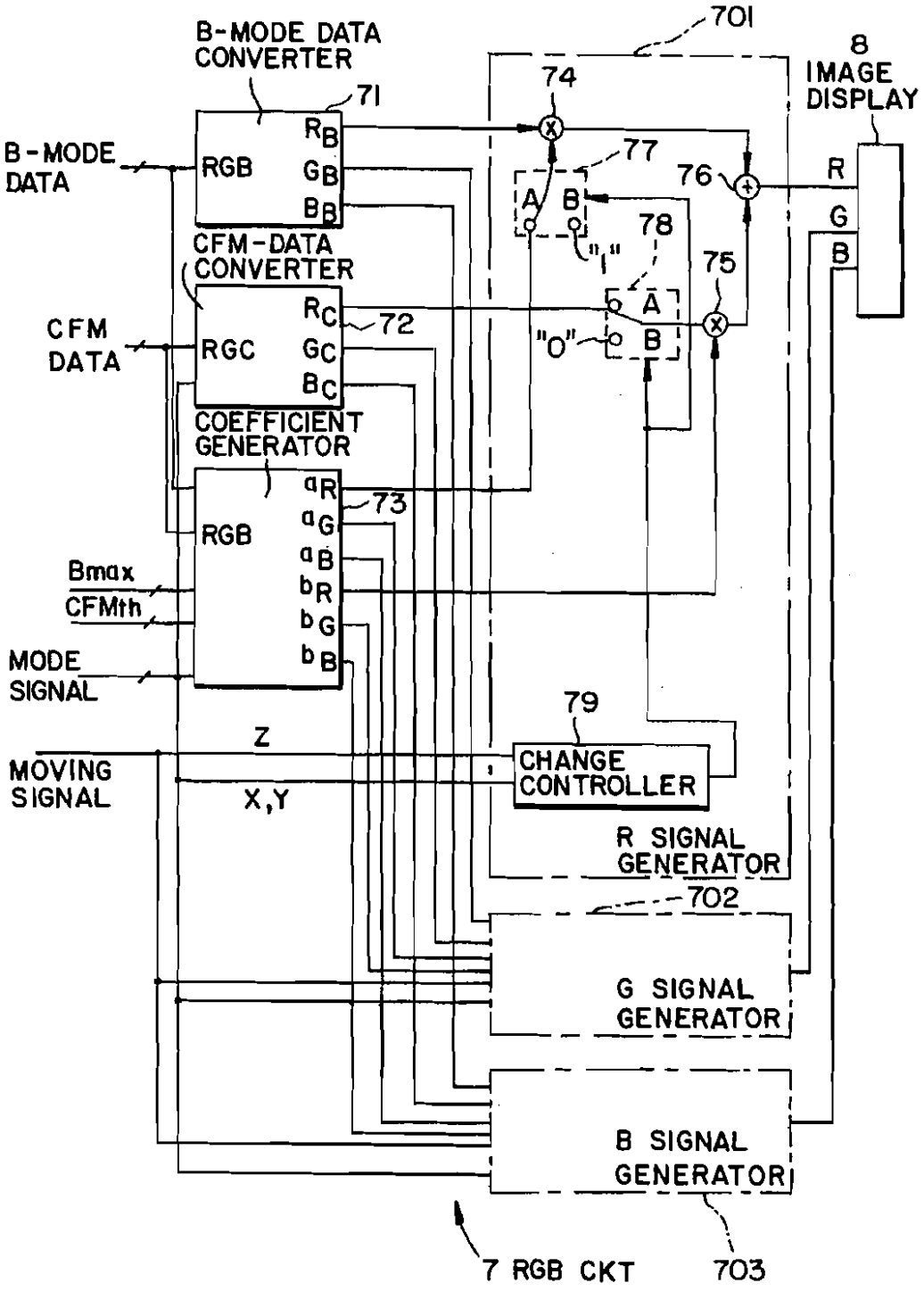


FIG. 1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B-MODE DATA
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R_B
G_B
B_B
CFM-DATA CONVERTER
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G_C
B_C
72
COEFFICIENT GENERATOR
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a_G
a_B
b_R
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73
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CFMth
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701
74
77
A
B
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78
76
75
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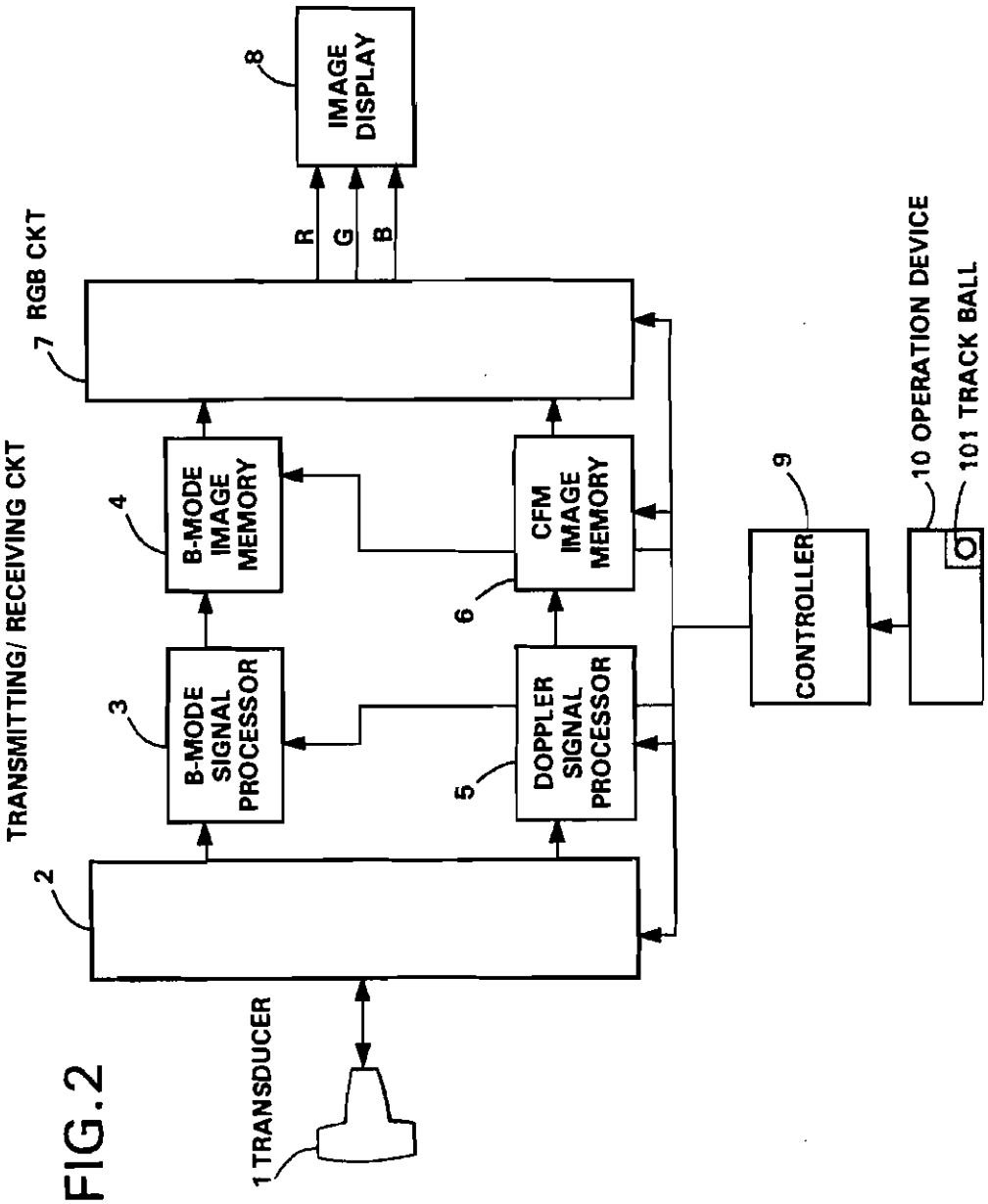
703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G
B
7 RGB CKT
TRANSMITTING/ RECEIVING CKT
4
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CFM IMAGE MEMORY
6
9
CONTROLLER
10 OPERATION DEVICE
101 TRACK BALL
3
B-MODE SIGNAL PROCESSOR
5
DOPPLER SIGNAL PROCESSOR
2
1 TRANSDUCER

FIG. 2

FIG. 3

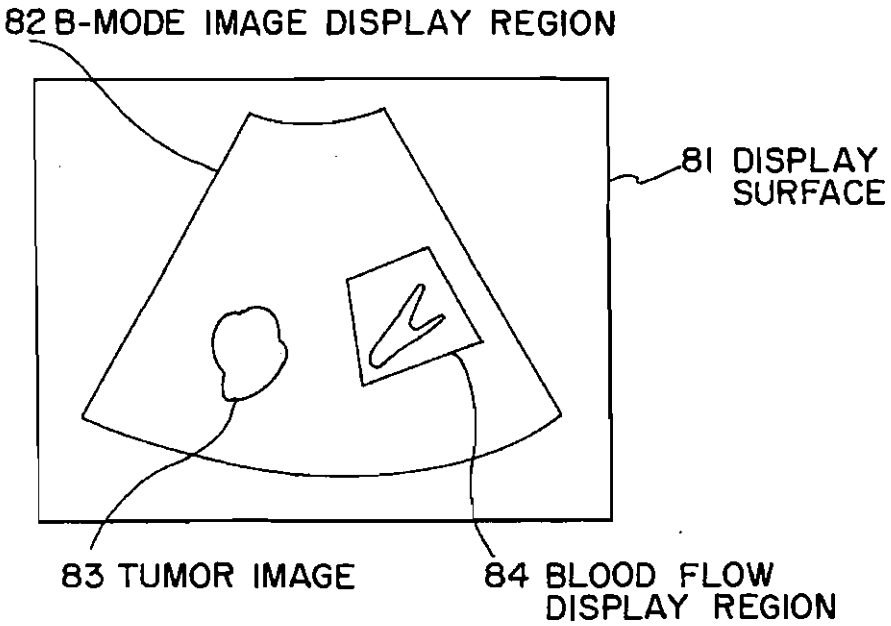
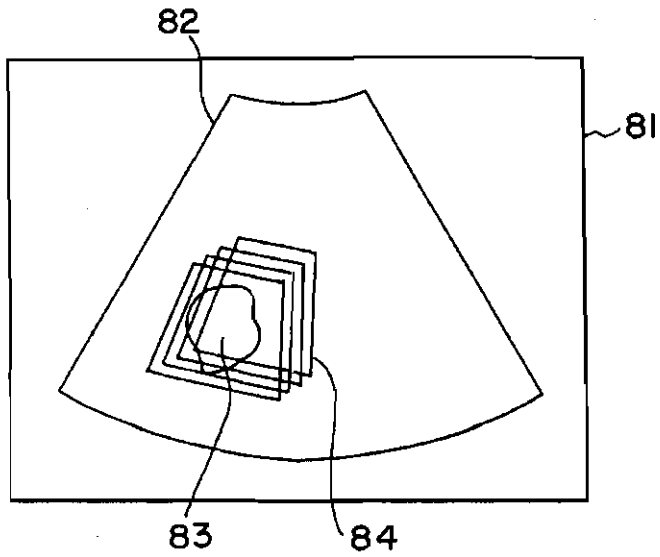

82 B-MODE IMAGE DISPLAY REGION
81 DISPLAY SURFACE
83 TUMOR IMAGE
84 BLOOD FLOW DISPLAY REGION

FIG. 4


82
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83
84

FIG. 5

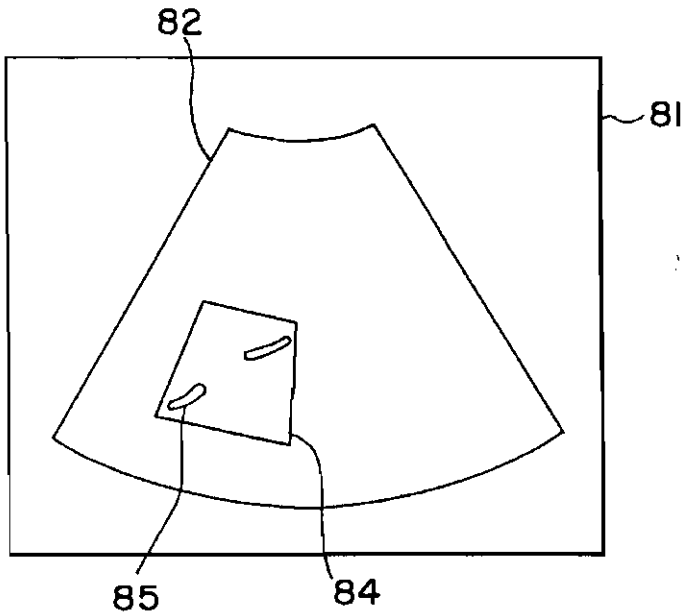
82
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FIG. 6

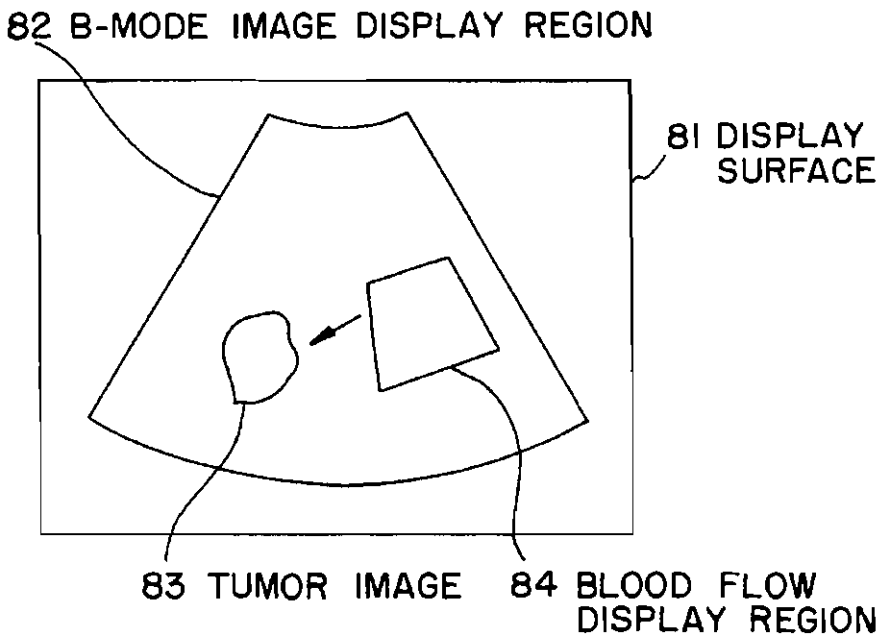
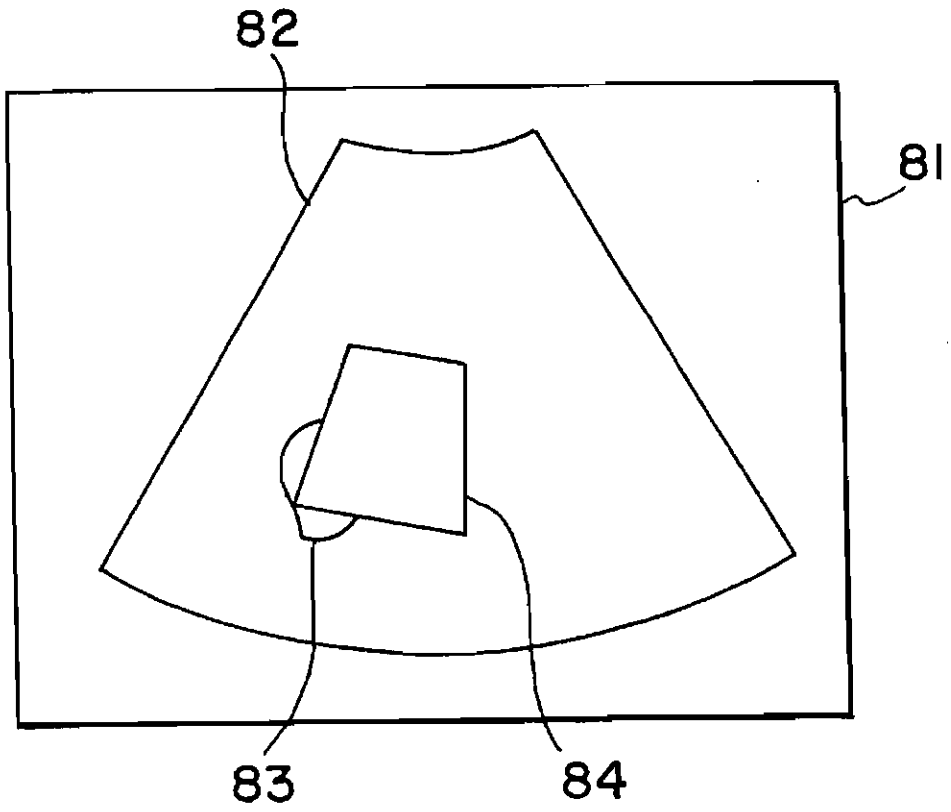

82 B-MODE IMAGE DISPLAY REGION
81 DISPLAY SURFACE
83 TUMOR IMAGE
84 BLOOD FLOW DISPLAY REGION

FIG. 7



METHOD AND APPARATUS FOR ULTRASONIC BLOOD FLOW DISPLAY

BACKGROUND OF THE INVENTION

In medical ultrasonic imaging apparatuses, ultrasonic wave is irradiated into an object to be examined and two-dimensional distribution of blood flow is displayed in a color image by power of a Doppler signal. Being different from a method of displaying blood flow by frequency of a Doppler signal, a method of displaying blood flow by power of a Doppler signal cannot display direction and speed of blood flow or speed dispersion but has unique function that existence of blood flow and its strength can be displayed at high sensitivity and high S/N ratio. In view of the unique function, this method becomes one of useful blood flow display methods.

In such an apparatus, as described in reference "Diagnostic Imaging", December 1993, pp 66–69, a blood flow display region is provided in a part of a B-mode image display region and a blood flow image is displayed in the blood flow display region. The blood flow display region can be moved freely in the B-mode image display region using an operation device, thereby a blood flow image in a desired region under study can be displayed.

The blood flow image is displayed by color corresponding to power of a Doppler signal, for example, by violet, red, orange, yellow in the rising order of the power. A portion without blood flow is displayed by color other than the above, e.g., by blue, and can be clearly distinguished from a portion with blood flow. Since a blood flow image by power of a Doppler signal has a good S/N ratio, a portion without blood flow is colored entirely with uniform blue.

Therefore as shown in FIG. **6** for example, when a tumor image **83** is displayed in a B-mode image display region **82** on a display surface **81** of an image display, in the case that a blood flow display region **84** is moved to a portion including the tumor image **83** so as to display blood flow of the portion, if the blood flow display region **84** overlaps with the tumor image **83** on the way of the moving as shown in FIG. **7**, the tumor image **83** is hidden and comes out of sight and the target cannot be confirmed.

In general, since an ultrasonic transducer, e.g., an ultrasonic probe is made touch an object to be examined by an operator, its direction is liable to vary. Therefore the deviation of the direction of the transducer must be corrected while viewing the screen, so that the tumor image **83** always appears on the display surface. However, if the target comes out of sight at the way of the moving as above described, even when the direction of the transducer is deviated, it cannot be corrected. Consequently it becomes unclear that the blood flow displayed on the blood flow display region **84** be blood flow at the desired portion certainly.

SUMMARY OF THE INVENTION

The present invention is in a method and an apparatus for ultrasonic blood flow display, where when a blood flow image in a power Doppler mode is displayed to a part of a B-mode image display region by ultrasonic wave, the B-mode image is displayed in place of the blood flow image while the blood flow display region is moved, and the blood flow image is displayed while the blood flow display region is stopped.

An object of the present invention is to realize a method and an apparatus for ultrasonic blood flow display where a B-mode image of a target can be easily caught even while a blood flow display region is moved.

The first invention is in a method for ultrasonic blood flow display where a blood flow image by power of an ultrasonic Doppler signal is displayed to a blood flow display region movable within a B-mode image display region, characterized in that the B-mode image is displayed within the blood flow display region while the blood flow display region is moved.

The second invention is in an apparatus for ultrasonic blood flow display comprising B-mode image forming means for forming a B-mode image based on an ultrasonic echo signal, blood flow image forming means for forming a blood flow image based on power of an ultrasonic Doppler signal, display means for displaying the B-mode image formed by the B-mode image forming means, and for displaying the blood flow image formed by the blood flow image forming means to the blood flow display region formed within the B-mode image display region, moving means for moving the blood flow display region, and display changing means for displaying the B-mode image within the blood flow display region while the blood flow display region is moved.

In the first invention, the B-mode image is displayed in the blood flow display region while the blood flow display region is moved, and the blood flow image is displayed in the blood flow display region when its moving is stopped.

In the second invention, according to the display changing means, the B-mode image is displayed in the blood flow display region while the blood flow display region is moved, and the blood flow image is displayed in the blood flow display region when its moving is stopped.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing configuration of main part of an apparatus in an embodiment of the invention;

FIG. **2** is a block diagram showing whole configuration of an apparatus in an embodiment of the invention;

FIG. **3** is an operation explanation diagram of an apparatus in an embodiment of the invention;

FIG. **4** is an operation explanation diagram of an apparatus in an embodiment of the invention;

FIG. **5** is an operation explanation diagram of an apparatus in an embodiment of the invention;

FIG. **6** is an operation explanation diagram of an apparatus in the prior art; and

FIG. **7** is an operation explanation diagram of an apparatus in the prior art.

DESCRIPTION OF THE PREFERRED EMBODIMENT

An embodiment of the present invention will be described in detail referring to the accompanying drawings as follows. In addition, the present invention is not limited by the embodiment. FIG. **1** is a block diagram showing configuration of main part of an apparatus in the embodiment of the present invention, and FIG. **2** is a block diagram showing whole configuration. In addition, a method of the embodiment of the present invention is shown in operation of the apparatus in the embodiment of the present invention.

First, explaining the whole configuration, in FIG. **2**, numeral **1** designates a transducer, numeral **2** designates a transmitting/receiving circuit, numeral **3** designates a

B-mode signal processor, numeral **4** designates a B-mode image memory, numeral **5** designates a Doppler signal processor, numeral **6** designates a CFM image memory, numeral **7** designates an RGB circuit, numeral **8** designates an image display, numeral **9** designates a controller, numeral **10** designates an operation device, and numeral **101** designates a track ball.

The transducer **1** is an ultrasonic probe for example, which is made touch an object to be examined (not shown) and irradiates ultrasonic wave into the object to be examined under control by the controller **9** according to a drive signal supplied from the transmitting/receiving circuit **2** and detects an echo signal returned from the inside of the object to be examined. The transmitting/receiving circuit **2** supplies a drive signal to the transducer **1**, and receives and amplifies detected echo signals and inputs the signals to the B-mode signal processor **3** and the Doppler signal processor **5** respectively.

The B-mode signal processor **3** processes an echo signal supplied from the transmitting/receiving circuit **2** under control by the controller **9**, and prepares image data for B-mode image display and writes the data in the B-mode image memory **4**. In this embodiment, the B-mode signal processor **3** corresponds to the B-mode image forming means in the present invention.

The Doppler signal processor **5** processes an echo signal supplied from the transmitting/receiving circuit **2** by a pulse Doppler method under control by the controller **9**, and prepares image data for displaying a CFM (Color Flow Mapping) image regarding blood flow dynamic state, i.e., respective image data (CFM data) representing rate of blood flow, power of the Doppler signal, dispersion of the blood flow rate or the like and writes the data in the CFM image memory **6**. In this embodiment, the Doppler signal processor **5** corresponds to the blood flow image forming means in the present invention.

The image data written in the B-mode image memory **4** and the CFM image memory **6** respectively are read out under control by the controller **9**, and converted into a plurality of color element signals for color display, e.g., RGB (Red, Green, Blue) signals by the RGB circuit **7** and supplied to the image display **8** and displayed as images there. In this embodiment, the RGB circuit **7** and the image display **8** correspond to the display means in the present invention.

The operation device **10** controls operation of the apparatus of this embodiment by operating the controller **9**. The operation device **10** is provided with a track ball **101** for moving a cursor or the like on the display surface of the image display **8**. The track ball **101** is operated also when the blood flow display region is moved. In this embodiment, the operation device **10** having the track ball **101** corresponds to the moving means in the present invention.

FIG. **1** is a detailed block diagram of the RGB circuit **7**. In FIG. **1**, numeral **71** designates a B-mode data RGB converter, numeral **72** designates a CFM data RGB converter, numeral **73** designates an RGB coefficient generator, and numerals **701**, **702** and **703** designate an R signal generator, a G signal generator and a B signal generator respectively.

The B-mode data RGB converter **71** converts B-mode data read out of the B-mode image memory **4** into RGB signals, and the CFM data RGB converter **72** converts CFM data read out of the CFM image memory **6** into RGB signals.

The RGB coefficient generator **73** generates coefficients of the RGB signals regarding the B-mode data and the CFM data respectively. The coefficients of the RGB signals of the B-mode data are a_R, a_G, a_B, and the coefficients of the RGB signals of the CFM data are b_R, b_G, b_B. Values of these coefficients are determined in range of 0 to 1.

Generation of these coefficients is determined according to the B-mode data, the CFM data, the threshold value B_{max}, the threshold value CFM_{TH} and mode signals, for example, by logic of following items (1), (2), (3). In addition, the threshold value B_{max}, the threshold value CFM_{TH} and the mode signals are supplied from the controller **9**.

(1) When values of the B-mode data exceed the prescribed threshold value B_{max}, the coefficients a_R, a_G, a_B are all made 1 and the coefficients b_R, b_G, b_B are all made 0. In addition, the threshold value B_{max} is provided so that the blood flow display for movement of organization of the object to be examined, i.e, for clutter component is prevented and artifact is not produced. The threshold value B_{max} is adjusted by the controller **9**.

(2) When values of the B-mode data are prescribed threshold value B_{max} or less and power values represented by the CFM data are the prescribed threshold value CFM_{TH} or more, the coefficients a_R, a_G, a_B are all made 0 and the coefficients b_R, b_G, b_B are all made 1. In addition, the threshold value CFM_{TH} in power display is provided in order to discriminate whether the portion during the signal processing is mainly the blood flow region (CFM_{TH} or more) or the organization region (less than CFM_{TH}). The threshold value CFM_{TH} is adjusted by the controller **9**.

(3) Otherwise, corresponding to the display mainly composed of B-mode images, the display mainly composed of CFM images or the display by compromise between both images, for example, (a_R=a_G=a_B=1, b_R=b_G=b_B=0), (a_R=a_G=a_B=0, b_R=b_G=b_B=1) or (a_R=a_G=a_B=0.6, b_R=b_G=b_B=0.3) is selected respectively. It is previously assigned which display should be selected.

Relation between logic of such items (1), (2), (3) and the image display will be described in detail in the later operation explanation. In addition, the RGB coefficient generator **73** having the logic function of the above-mentioned (1), (2), (3) is preferably constituted by the logic circuit of hardware from the viewpoint that the operation speed can be made high speed. However, the same function can be implemented by a program of a micro computer or the like. This case is advantageous in that the measure to changing, revision or the like becomes easy.

The R signal generator **701** comprises multipliers **74**, **75**, an adder **76**, changers **77**, **78** and a change controller **79**.

The multiplier **74** multiplies the R signal R_B of the B-mode data outputted from the B-mode data RGB converter **71** by the output coefficient a_R of the RGB coefficient generator **73** or the fixed coefficient **1** supplied through the changer **77**.

The multiplier **75** multiplies the R signal R_C of the CFM data from the CFM data RGB changer **72** or the fixed data **0** supplied through the changer **78** by the output coefficient b_R of the RGB coefficient generator **73**.

The adder **76** adds output signals of these multipliers **74**, **75**, and supplies the result as the R signal for display to the image display **8**.

The change controller **79** controls changing of the changers **77**, **78**, and the control of the changing is carried out according to a mode signal and a moving signal supplied from the controller **9**. In addition, the moving signal is a signal indicating that the blood flow display region is being moved.

The mode signal is a signal representing, for example, four sorts of modes, i.e., B mode, speed mode, power mode and dispersion mode, in two bits, and the moving signal is a signal representing whether the blood flow display region is being moved or not in one bit.

Based on these signals, the change controller **79** controls changing of the changers **77**, **78** according to logic of following items (4), (5), (6).

(4) When the mode signal indicates the B mode, the changers **77**, **78** are changed to the side of the contact B.

(5) When the mode signal indicates the power mode and the moving signal indicates "moving", the changers **77**, **78** are changed to the side of the contact B.

(6) Otherwise, the changers **77**, **78** are changed to the side of the contact A.

Table 1 shows relation between input signals and output signals of such a change controller **79**.

TABLE 1

mode	movement XY[Z]	moving 1	not moving 0
B	00	1	1
speed	01	0	0
power	11	1	0
dispersion	10	0	0

Table 1 shows logic values of the output signal Q of the change controller **79** to logic values of the input signals X, Y of two bits representing modes and the input signal Z of one bit representing moving of the blood flow display region. In addition, Q=0 indicates a changing signal to the side of the contact A, and Q=1 indicates a changing signal to the side of the contact B.

Logical expression of the output signal Q satisfying Table 1 is shown by following formula 1.

Formula 1

$$Q=\bar{X}\bar{Y}+XYZ$$

The G signal generator **702** and the B signal generator **703** also have similar configuration to that of the R signal generator **701**, and generate the G signal and the B signal for display respectively and supply the signals to the image display **8**.

The R signal generator **701**, the G signal generator **702** and the B signal generator **703** are preferably constituted by the logical circuit of hardware from the viewpoint that the operation speed can be made high speed, but the same function as that of the multipliers **74**, **75**, the adder **76**, the changers **77**, **78** and the change controller **79** can be implemented by the program of the micro computer or the like. This case is advantageous in that the measure to changing, revision or the like becomes easy.

Operation of the apparatus in such configuration will be described as follows. FIGS. **3** to **5** are diagrams showing an example of image display by the apparatus in the embodiment of the present invention. In addition, these diagrams show also an example of image display by the method in the embodiment of the present invention.

First as shown in FIG. **3**, in the display surface **81** of the image display **8**, state of displaying the B-mode image to the B-mode image display region **82** and carrying out the blood flow display of the power mode to the blood flow display region **84** will be described. In addition, the blood flow display region **84** is clearly indicated by contour line on the screen.

The state of FIG. **3** is the power mode, but when the blood flow display region **84** is stopped, in the R signal generator **701** of the RGB circuit **7**, the changers **77**, **78** are changed to the side of the contact A by the controller **79**.

Therefore the multiplier **74** multiplies the output signal R_B of the B-mode data RGB converter **71** by the output coefficient a_R Of the RGB coefficient generator **73**, and the multiplier **75** multiplies the output signal R_C of the CFM data RGB converter **72** by the output coefficient b_R of the RGB coefficient generator **73**, and the output signals of these two multipliers **74**, **75** are added by the adder **76** and supplied as the R signal for display to the image display **8**.

The G signal generator **702** and the B signal generator **703** also are in similar operation state and form the G signal and the B signal for display respectively, which are supplied to the image display **8**.

Since the RGB coefficient generator **73** generate the coefficient a_R, a_G, a_B and the coefficients b_R, b_G, b_B according to the logic of (1) to (3), the image display **8** is supplied with following RGB signals.

(1)' When values of the B-mode data exceed the threshold value B_{max}, since the coefficients a_R, a_G, a_B are all 1 and the coefficients b_R, b_G, b_B are all 0, in the R signal generator **701**, the output signal R_B of the B-mode data RGB converter **71** is multiplied by 1 in the multiplier **74**, and the output signal R_C of the CFM data RGB converter **72** is multiplied by 0 in the multiplier **75**. As a result, the output signal of the adder **76** becomes the R signal by only the B mode data. The G signal generator **702** and the B signal generator **703** also output the G signal and the B signal by only the B-mode data respectively. Consequently the B-mode image is displayed in the image display **8**.

(2)' When values of the B-mode data are the threshold value B_{max} or less and power values of blood flow represented by the CFM data are the threshold value CFM_{TH} or more, since the coefficients a_R, a_G, a_B are all 0 and the coefficients b_R, b_G, b_B are all 1, in the R signal generator **701**, the output signal R_B of the B-mode data RGB converter **71** is multiplied by 0 in the multiplier **74**, and the output signal R_C of the CFM data RGB converter **72** is multiplied by **1** in the multiplier **75**. As a result, the output signal of the adder **76** becomes the R signal by only the CFM data. The G signal generator **702** and the B signal generator **703** also output the G signal and the B signal by only the CFM data respectively. Consequently the blood flow image is displayed in the image display **8**.

(3)' When values of the B mode data are the threshold value B_{max} or less and power values of blood flow represented by the CFM data are less than the threshold value CFM_{TH}, corresponding to the display mainly composed of B-mode images, the display mainly composed of CFM images or the display by compromise between both images, each coefficient becomes, for example, ($a_R=a_G=a_B=1$, $b_R=b_G=b_B=0$), ($a_R=a_G=a_B=0$, $b_R=b_G=b_B=1$) or ($a_R=a_G=a_B=0.6$, $b_R=b_G=b_B=0.3$) respectively. Consequently, in the image display **8**, only the B-mode image is displayed in the display mainly composed of B-mode images, and only the blood flow image is displayed in the display mainly composed of CFM images, and the B-mode image and the blood flow image are displayed to overlap each other in semitransparent state in the display by compromise between both images.

Thus, since the RGB signal of the B mode data and the RGB signal of the CFM data are added with the output coefficient of the RGB coefficient generator **73** and becomes

the RGB signals for image display, the displayed image as shown in FIG. 3 displays the B-mode image including the tumor image **83** in the B-mode image display region **82** and displays the blood flow image in the blood flow display region **84**.

Next, description will be done regarding the case that the track ball **101** is operated and the blood flow display region **84** is moved to the portion of the tumor image **83** and the blood flow of the portion is displayed.

If the blood flow display region **84** is moved, since the moving signal indicates "moving" during the moving, the change controller **79** changes the changers **77**, **78** to the side of the contact B. Thereby since the multiplier **74** multiplies the output R_B of the B-mode data RGB converter **71** by the fixed coefficient **1** and the multiplier **75** multiplies the fixed data **0** by the coefficient b_R, the output signal of the adder **76** becomes only the R signal of the B-mode image. Also in the G signal generator **702** and the B signal generator **703**, similar operation is carried out and the G signal and the B signal of the B-mode image are outputted respectively.

Therefore display of the blood flow is inhibited and the B-mode image is displayed also in the blood flow display region **84**. Consequently as shown in FIG. 4, even if the blood flow display region **84** being moved overlaps with the tumor image **83**, since the tumor image **83** appears, the target does not come out of sight. That is, effect is obtained in that the B-mode image of the target can be easily caught even while the blood flow display region **84** is moved.

Also even if the direction of the transducer **1** is deviated at the way of moving and the tumor image **83** disappears, the direction is searched while viewing the screen, thereby the tumor image **83** of the target can be projected again. That is, effect is obtained in that the correct direction of the transducer **1** can be easily secured while the blood flow display region **84** is moved.

If the tumor image **83** of the target entirely enters the blood flow display region **84**, then operation of the track ball **101** is stopped and the moving of the display region is stopped. Thereby since the moving signal becomes "not moving", the change controller **79** returns the changers **77**, **78** to the side of the contact A so that the R signals based on the B mode data and the CFM data are supplied to the image display **8**. Also in the G signal generator **702** and the B signal generator **703**, similar operation is carried out.

As a result, as shown in FIG. **5**, the blood flow at the portion securely recognized as the tumor image **83** is displayed in the blood display region **84**. That is, effect is obtained in that the blood flow at the desired portion can be displayed securely.

In addition, the display means is not limited to that where the image is color-displayed by the RGB signal as in the embodiment, but the display means carrying out the color display by other plural color element signals will do. Further even the display means displaying the blood flow not by color but by tone of monochrome or specific pattern (hatching or the like) belongs to scope of the display means in the present invention.

Also the moving means is not limited to the track ball as in the embodiment, but various sorts of operation tools for the figure moving, such as a mouth, a joy stick, a cursor key, a touch panel or the like, are included in scope of the moving means in the present invention.

Also the display changing means is not limited to the micro computer or the like comprising the changers **77**, **78** and the changing controller **79** having hardware or software of the same function as in the embodiment. The display changing means, in short, may be that changing the display mode of the screen into the B-mode display while the blood flow display region is moved, and the display changing means having this function is included in scope of the display changing means in the present invention.

As above described in detail, in the present invention, since the B-mode image is displayed within the blood flow display region while the blood flow display region is moved, the B-mode image is displayed in the blood flow display region while the blood flow display region is moved and the blood flow image is displayed in the blood flow display region when the moving is stopped. Therefore effect is obtained in that the B-mode image of the target can be easily caught even while the blood flow display region is moved.

What is claimed is:

1. A method for ultrasonic blood flow display where a blood flow image by power of an ultrasonic Doppler signal is displayed to a blood flow display region movable within a B-mode image display region,

characterized in that the B-mode image is displayed within said blood flow display region while said blood flow display region is moved.

2. An apparatus for ultrasonic blood flow display, comprising:

B-mode image forming means for forming a B-mode image based on an ultrasonic echo signal;

blood flow image forming means for forming a blood flow image based on power of an ultrasonic Doppler signal;

display means for displaying the B-mode image formed by said B-mode image forming means, and for displaying the blood flow image formed by said blood flow image forming means to a blood flow display region formed within a B-mode image display region;

moving means for moving said blood flow display means; and

display changing means for displaying the B-mode image within said blood flow display region while said blood flow display region is moved.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,584,294

DATED : December 29, 1998

INVENTOR(S) : HIROSAWA et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 12, line 51, delete "extension" and insert –extrusion–.

Signed and Sealed this

Twenty-ninth Day of May, 2001

Attest:

Nicholas P. Godici

NICHOLAS P. GODICI

Attesting Officer

Acting Director of the United States Patent and Trademark Office

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,584,294
DATED : December 17, 1996
INVENTOR(S) : Shinichi Amemiya, et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

This certificate supercedes certificate of correction issued May 29, 2001, the number was erroneously mentioned and should be deleted since no Certificate of Correction was granted.

Signed and Sealed this

Twenty-first Day of August, 2001

Attest:

Nicholas P. Godici

Attesting Officer

NICHOLAS P. GODICI
Acting Director of the United States Patent and Trademark Office

EXHIBIT C

US006120447A

United States Patent [19]

Mullen

[11] Patent Number: 6,120,447

[45] Date of Patent: Sep. 19, 2000

[54] **ULTRASOUND IMAGE DATA WIRELESS TRANSMISSION TECHNIQUES**

[75] Inventor: **Paul Mullen**, Waukesha, Wis.

[73] Assignee: **General Electric Company**, Milwaukee, Wis.

[21] Appl. No.: **09/224,454**

[22] Filed: **Dec. 31, 1998**

[51] **Int. Cl.**[7] **A61B 8/00**

[52] **U.S. Cl.** **600/437**

[58] **Field of Search** 600/437, 443; 128/903, 904; 395/200.5, 200.53, 200.3, 200.31; 705/2, 3

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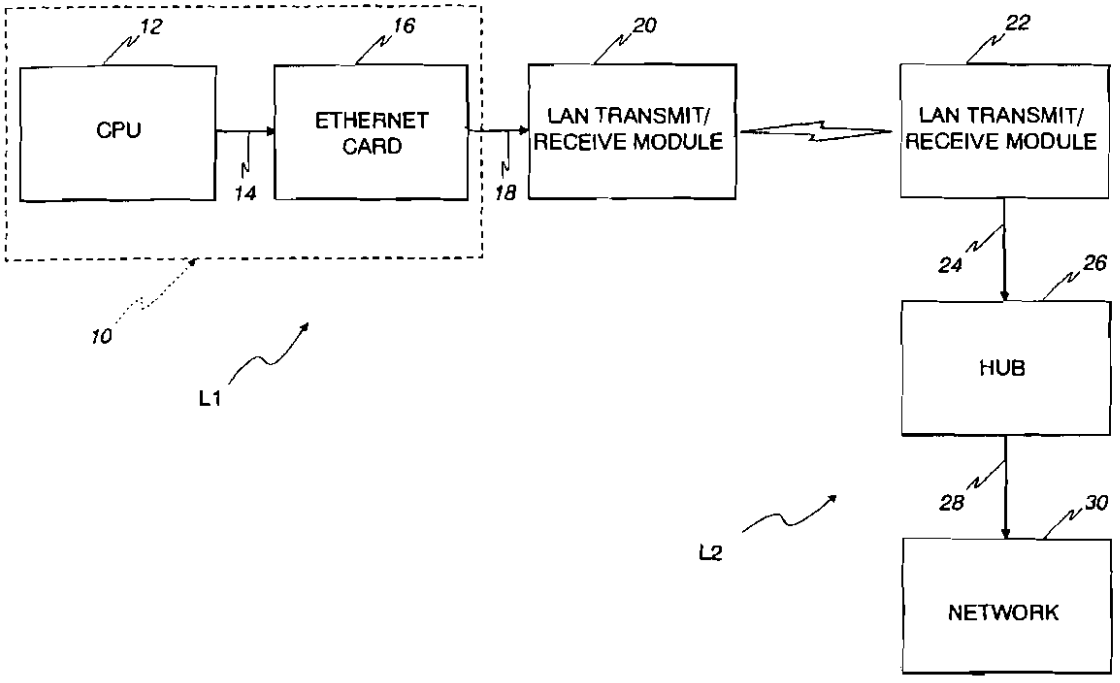
Primary Examiner—Francis J. Jaworski

Attorney, Agent, or Firm—McAndrews Held & Malloy; Christian G. Cabou; Phyllis Y. Price

[57] **ABSTRACT**

An ultrasound imaging system transmits data wirelessly by means of transmit and receive modules so that the data may be transferred to a network. Data also may be transmitted from the network wirelessly through modules to the ultrasound imaging system in order to control the system.

13 Claims, 1 Drawing Sheet



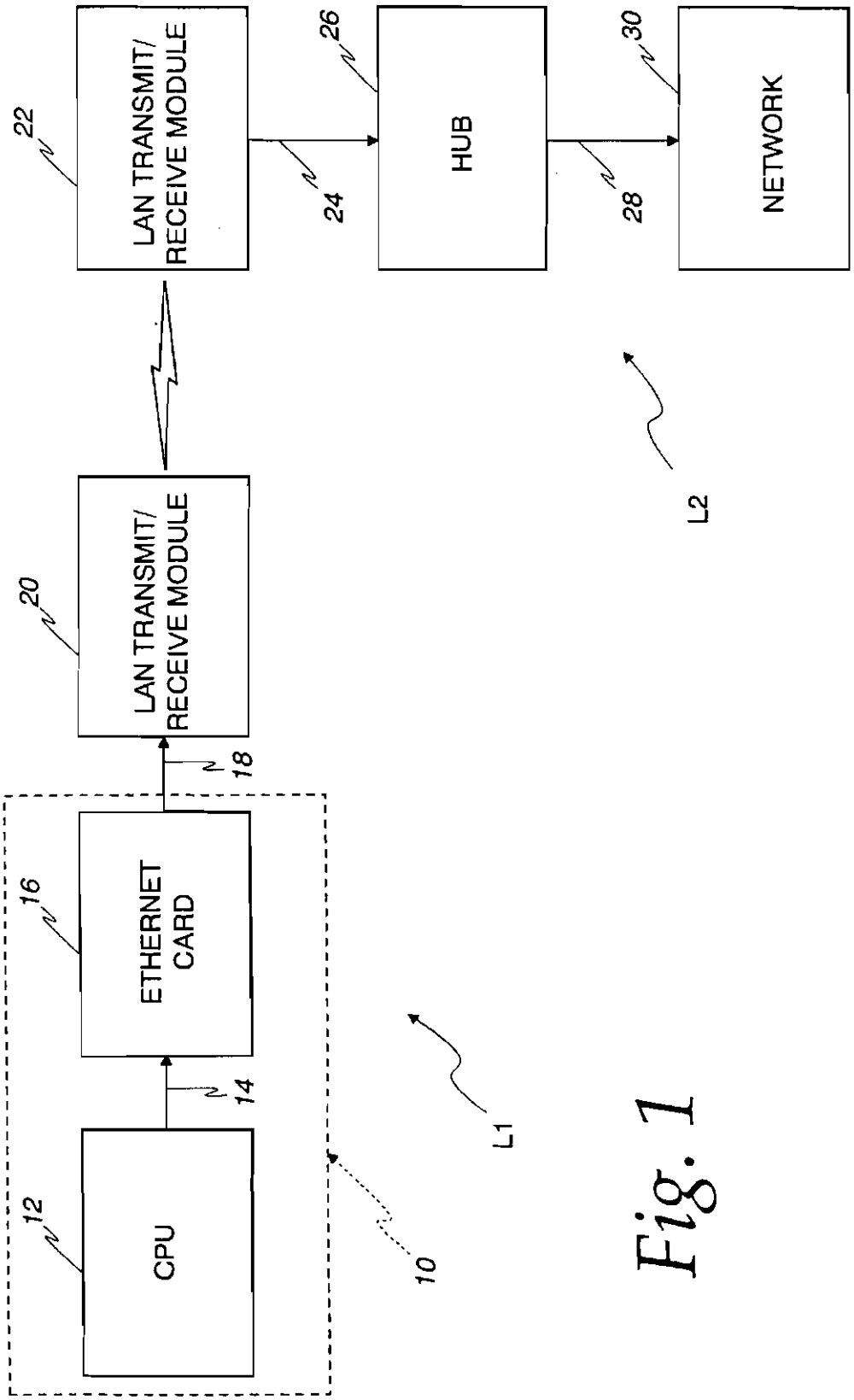

LAN TRANSMIT/ RECEIVE MODULE
22
24
HUB
26
28
NETWORK
30
L2
LAN TRANSMIT/ RECEIVE MODULE
20
18
ETHERNET CARD
16
14
CPU
12
L1
10

Fig. 1

ULTRASOUND IMAGE DATA WIRELESS TRANSMISSION TECHNIQUES

CROSS-REFERENCE TO RELATED APPLICATIONS

Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

BACKGROUND OF THE INVENTION

This invention relates to ultrasound imaging systems and more specifically relates to the transmission of data resulting from such systems.

Presently known ultrasound imaging systems generate image data which must be stored in a data base maintained in a storage device remote from the imaging system itself. The transmission of the data requires wires or cables which must be connected from the imaging system to the storage device.

Ultrasound imaging systems frequently are moved from bed to bed in a hospital ward. In such an environment, the wires required for data transmission become entangled in the beds or other equipment in the ward, and generally impede the progress of the ultrasound scanning. This invention solves these problems.

BRIEF SUMMARY OF THE INVENTION

This invention is useful in an ultrasound imaging system for generating image data in response to scanning of a subject under study. In order to implement the preferred embodiment of the invention, image data is generated by scanning a subject under study, preferably by operating an ultrasound imaging system. The image data is transmitted from a first location wirelessly using a network protocol. Preferably, the transmission is carried out by a network card and a network transmit module. The wirelessly transmitted image data is received at a second location different from the first location, preferably by a network receive module.

By using the foregoing techniques, image data may be generated by an ultrasound imaging system and may be transmitted without wires to a network. The network preferably is connected to a data image storage device. These techniques facilitate the movement of the ultrasound imaging system in a hospital ward and enable the ultrasound scanning to be carried out with a degree of convenience and efficiency previously unattainable.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic block diagram of a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, a conventional ultrasound imaging system **10** is located in a location L1 and comprises a central processing unit **12** which communicates image data over a bus **14** to a local area network Ethernet card **16**. The ultrasound scanning system may comprise, for example, the scanning systems bearing model numbers 700, 500 or 400 which are sold under the trademark LOGIQ by the Medical Systems Division of General Electric Company, Milwaukee, Wis. Such systems include a CPU **12** and an Ethernet network interface card **16** as shown in FIG. 1.

The image data is transmitted over a bus **18** to a conventional local area network transmit/receive module **20**. Such modules are known to those skilled in the art. One exemplary module is model 364020-1 manufactured by AMP Corporation and sold under the trademark "Access Point 2". Module **20** transforms the image data into radio frequency signals which are transmitted wirelessly to a second location L2 and are received by another local area network transmit/receive module **22** which may identical to module **20**.

The image data received at location L2 is transmitted over a bus **24** to a routing device, such as a HUB **26**. The image data is then routed over a bus **28** to a network **30**. Network **30** may be either an asynchronous network using the internet protocol or asynchronous network which transports ATM cells over conventional telephone switching equipment. Alternatively, network **30** may be a local area network connected to a data storage device capable of storing the image data.

Data received by network **30** may be transmitted through hub **26** and into module **22** and transmitted from module **22** to module **20**. The receive data may be converted to the Ethernet protocol and transmitted to CPU **12** in order to help control system **10**.

By using the foregoing techniques, image data may be transmitted wirelessly from imaging system **10** and data may be received wirelessly in order to provide control for imaging system **10**.

Those skilled in the art will recognize that the preferred embodiment may be altered and modified without departing from the true spirit and scope of the invention as defined in the accompanying claims.

What is claimed is:

1. In an ultrasound imaging system for generating image data at a first location in response to scanning of a subject under study, improved apparatus for transmitting the data comprising in combination:

a computer connected to control the ultrasound imaging system;

a network interface connected to receive the image data from the computer;

a network transmit module coupled to the network interface connected to wirelessly transmit the image data before storage;

a network receive module connected to receive the wirelessly transmitted image data at a second location remote from the first location;

a routing device connected to route the received image data; and

an asynchronous network for transmitting the received data via internet protocol, whereby image data generated by the ultrasound imaging system may be transmitted without wires to a network before storage.

2. Apparatus, as claimed in claim **1**, wherein the network interface is a local area network interface.

3. Apparatus, as claimed in claim **1**, wherein the network transmit module comprises a local area network transmit module.

4. Apparatus, as claimed in claim **1**, wherein the network receive module comprises a local area network receive module.

5. Apparatus, as claimed in claim **1**, and further comprising a routing module connected to route the image data to a network from the network receive module.

6. Apparatus, as claimed in claim **5**, wherein the routing module comprises a hub.

7. Apparatus, as claimed in claim 1, wherein the network transmit module also comprises a network receive module.

8. Apparatus, as claimed in claim 1, wherein the network receive module also comprises a network transmit module.

9. In an ultrasound imaging system for generating image data at a first location in response to scanning of a subject under study, an improved method of transmitting the data comprising in combination:

generating image data by scanning a subject under study;

transmitting the image data wirelessly using a network protocol from the first location before storage;

receiving the wirelessly transmitted image data at a second location different from the first location;

asynchronously transmitting the received image data using internet protocol, whereby the image data may be routed to a network before storage.

10. A method, as claimed in claim 9, wherein the network protocol comprises a local area network protocol.

11. A method, as claimed in claim 9, wherein the network protocol comprises an Ethernet protocol.

12. A method, as claimed in claim 9, and further comprising the step of routing the image data to a network.

13. A method, as claimed in claim 9, and further comprising the step of receiving wirelessly transmitted data at the ultrasound imaging system.

* * * * *

EXHIBIT D

US006210327B1

(12) **United States Patent**
Brackett et al.

(10) **Patent No.: US 6,210,327 B1**
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(54) **METHOD AND APPARATUS FOR SENDING ULTRASOUND IMAGE DATA TO REMOTELY LOCATED DEVICE**

(75) Inventors: **Charles C. Brackett**, Waukesha; **Gregory C. Stratton**, Wauwatosa; **James S. Lehoullier**, Waukesha; **Jeannette M. Elchholz**, West Allis; **Takao Shiibashi**, Brookfield, all of WI (US)

(73) Assignee: **General Electric Company**, Milwaukee, WI (US)

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(52) **U.S. Cl.** **600/437**; 600/407
(58) **Field of Search** 600/437, 407, 600/410, 443, 447; 128/903, 922; 395/701, 703, 705, 280, 680, 726; 345/156, 329, 520; 705/2, 3; 707/200, 500, 513; 713/100

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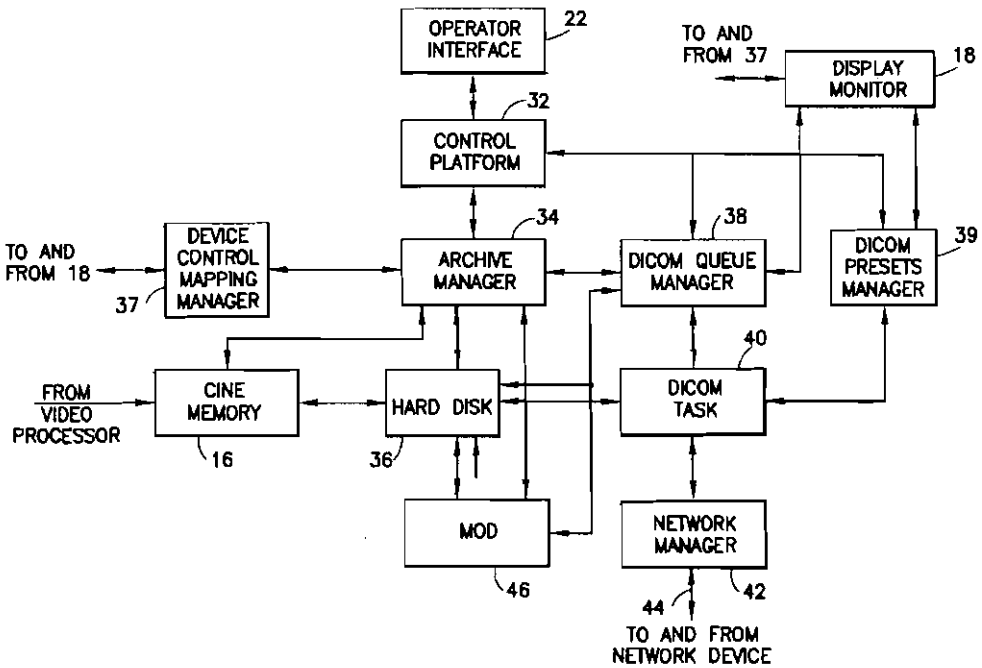
Primary Examiner—Francis J. Jaworski
(74) *Attorney, Agent, or Firm*—Dennis M. Flaherty; Christian G. Cabou; Phyllis Y. Price

(57) **ABSTRACT**

A computerized ultrasound imager is programmed with software that enables a "Live Imaging" mode. "Live Imaging" refers to the ability to keep a network association (between the imager and a remote device) open throughout the course of an examination of a patient. Each time the operator presses a Print/Store button configured to a storage device, the frozen image will be automatically sent to the remote device via the open connection. The "Live Imaging" association is closed when the system operator presses an "End Exam" button on the keyboard. In the case where the remote device is a printer configured to receive multi-image film sessions, pressing the "End Exam" button also forces the transfer of any partially filled film session from the imager to the printer.

15 Claims, 6 Drawing Sheets



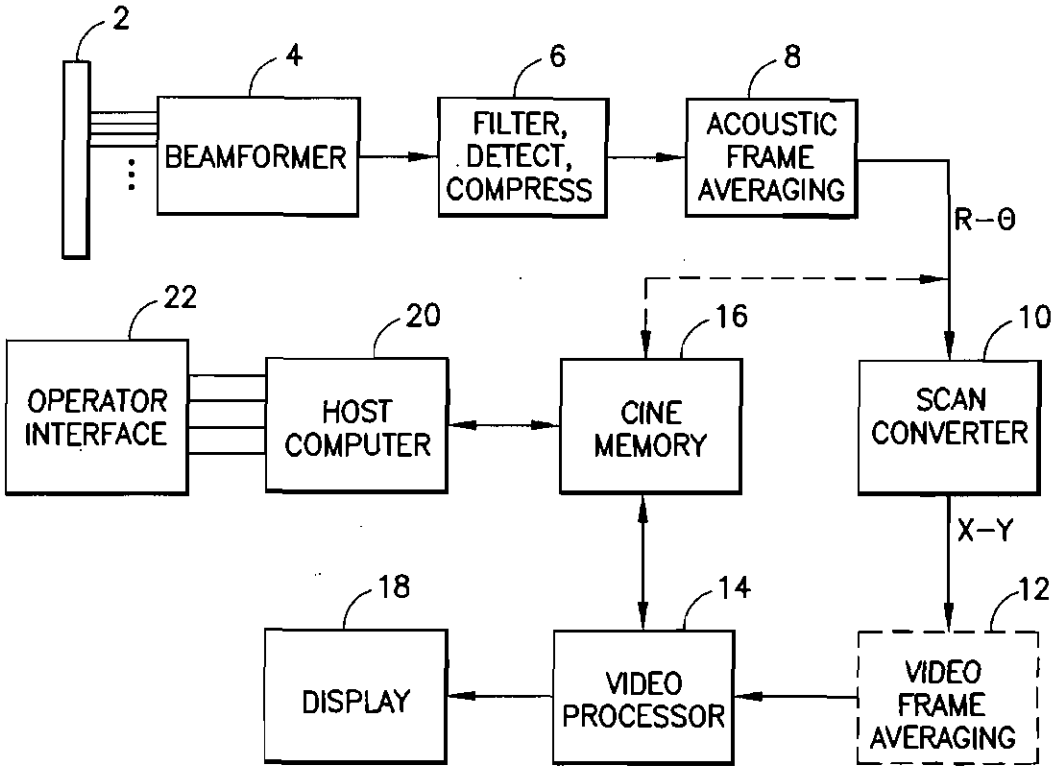

2
4
6
8
BEAMFORMER
FILTER, DETECT, COMPRESS
ACOUSTIC FRAME AVERAGING
R–θ
22
20
16
10
OPERATOR INTERFACE
HOST COMPUTER
CINE MEMORY
SCAN CONVERTER
X–Y
18
14
12
DISPLAY
VIDEO PROCESSOR
VIDEO FRAME AVERAGING

FIG. 1

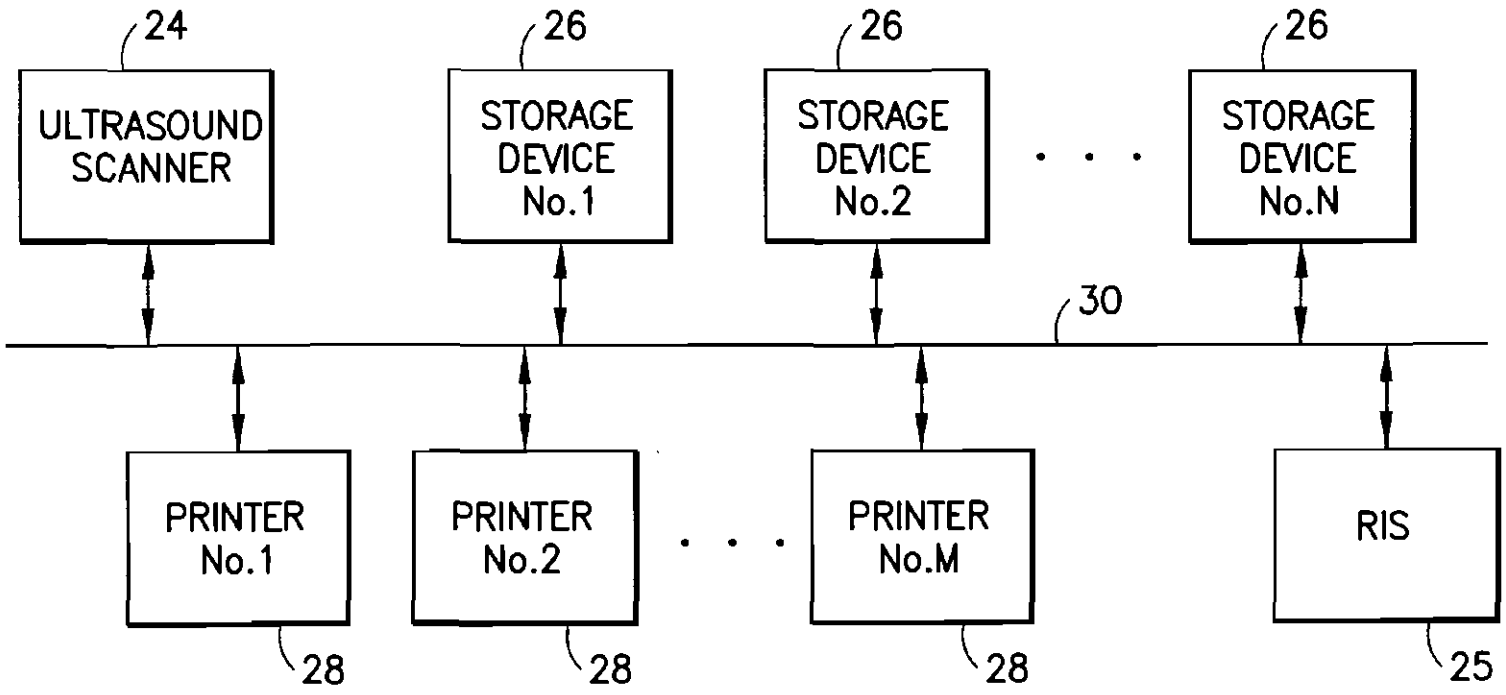

24
ULTRASOUND SCANNER
26
STORAGE DEVICE No.1
26
STORAGE DEVICE No.2
26
STORAGE DEVICE No.N
30
PRINTER No.1
PRINTER No.2
PRINTER No.M
RIS
28
28
28
25

FIG.2

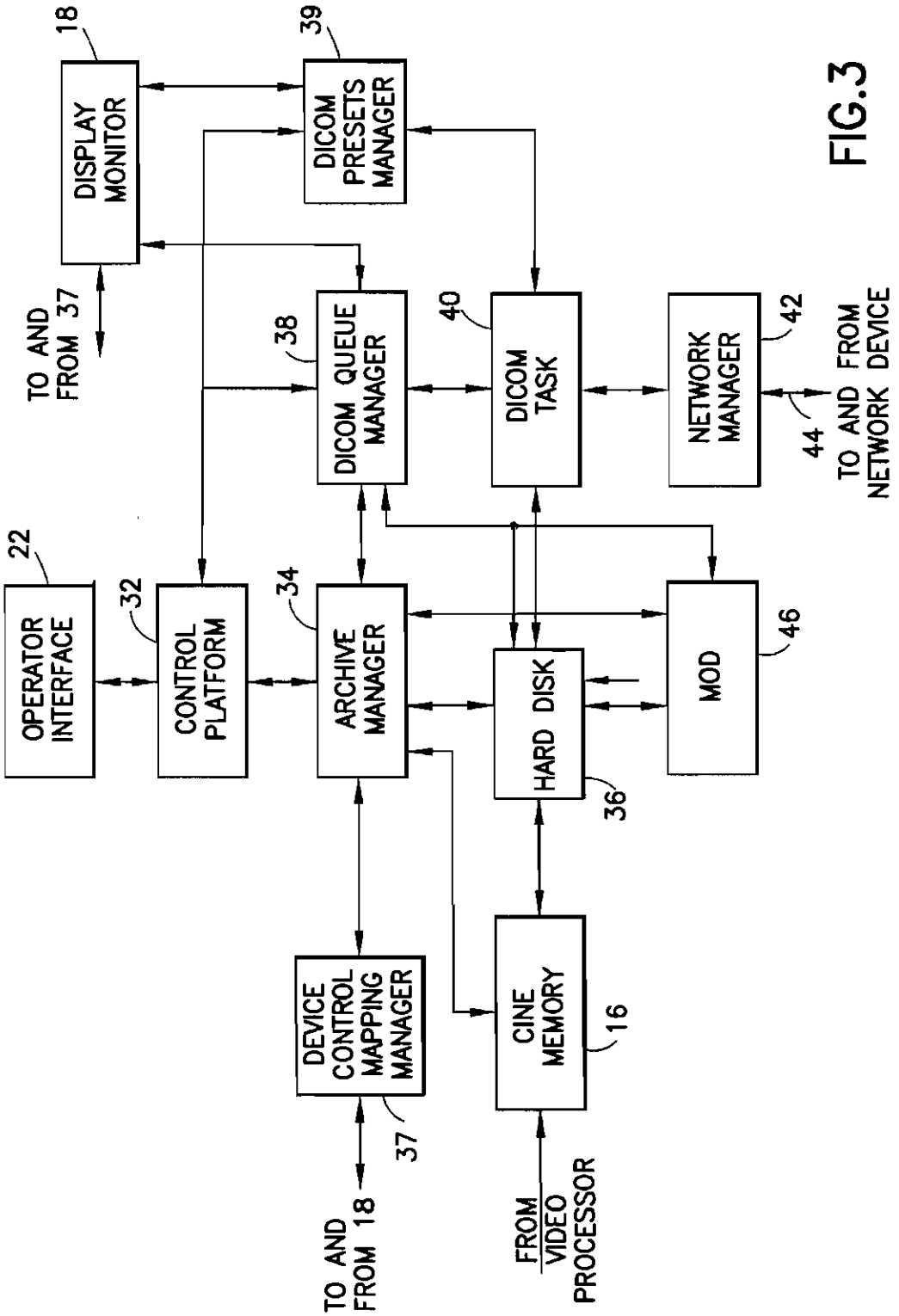

18
DISPLAY MONITOR
39
DICOM PRESETS MANAGER
TO AND FROM 37
38
DICOM QUEUE MANAGER
40
DICOM TASK
NETWORK MANAGER
42
44
TO AND FROM NETWORK DEVICE
22
OPERATOR INTERFACE
32
CONTROL PLATFORM
34
ARCHIVE MANAGER
HARD DISK
36
MOD
46
DEVICE CONTROL MAPPING MANAGER
37
CINE MEMORY
16
TO AND FROM 18
FROM VIDEO PROCESSOR

FIG.3

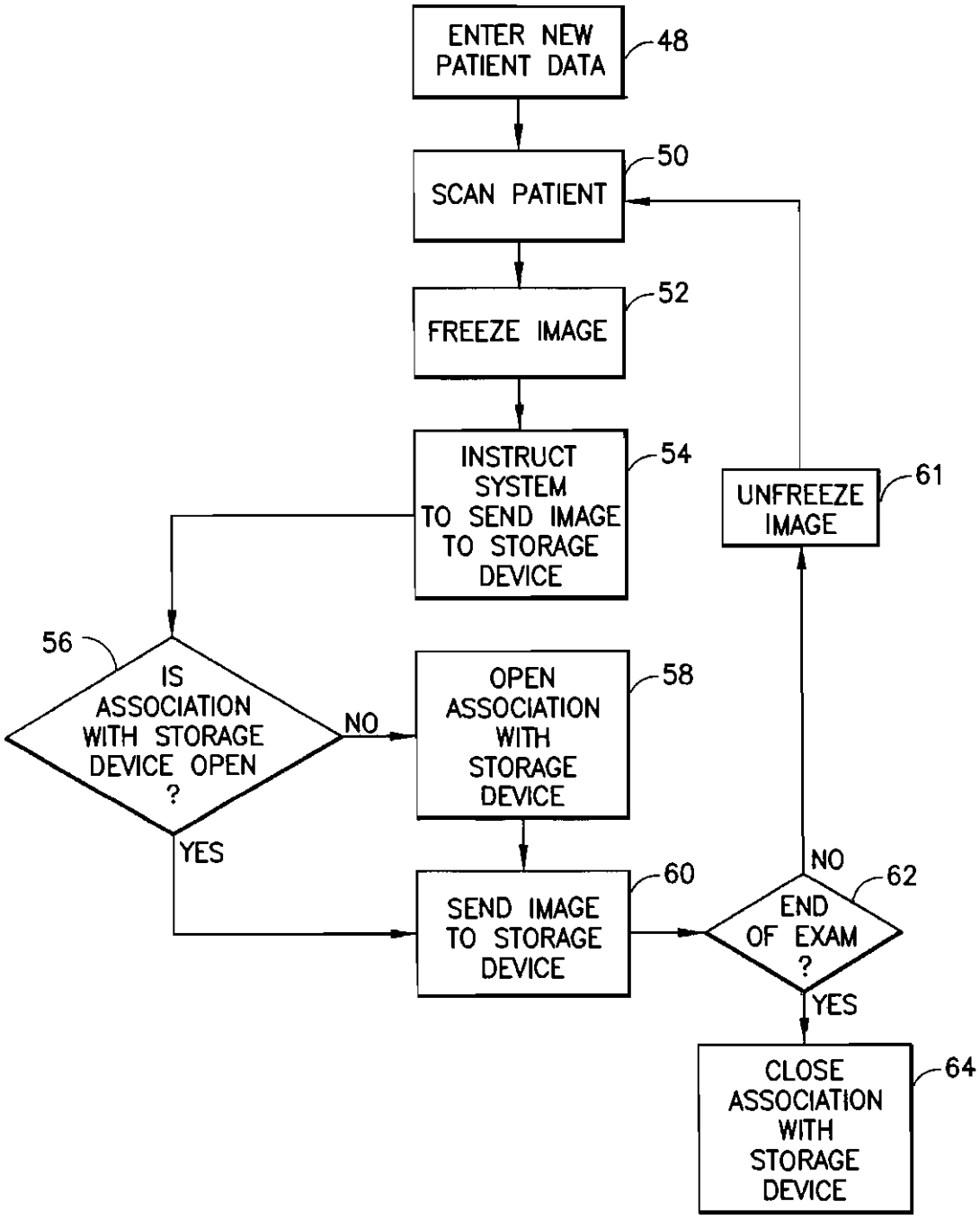

ENTER NEW PATIENT DATA
48
SCAN PATIENT
50
FREEZE IMAGE
52
INSTRUCT SYSTEM TO SEND IMAGE TO STORAGE DEVICE
54
UNFREEZE IMAGE
61
56
IS ASSOCIATION WITH STORAGE DEVICE OPEN ?
NO
OPEN ASSOCIATION WITH STORAGE DEVICE
58
YES
SEND IMAGE TO STORAGE DEVICE
60
NO
END OF EXAM ?
62
YES
CLOSE ASSOCIATION WITH STORAGE DEVICE
64

FIG.4

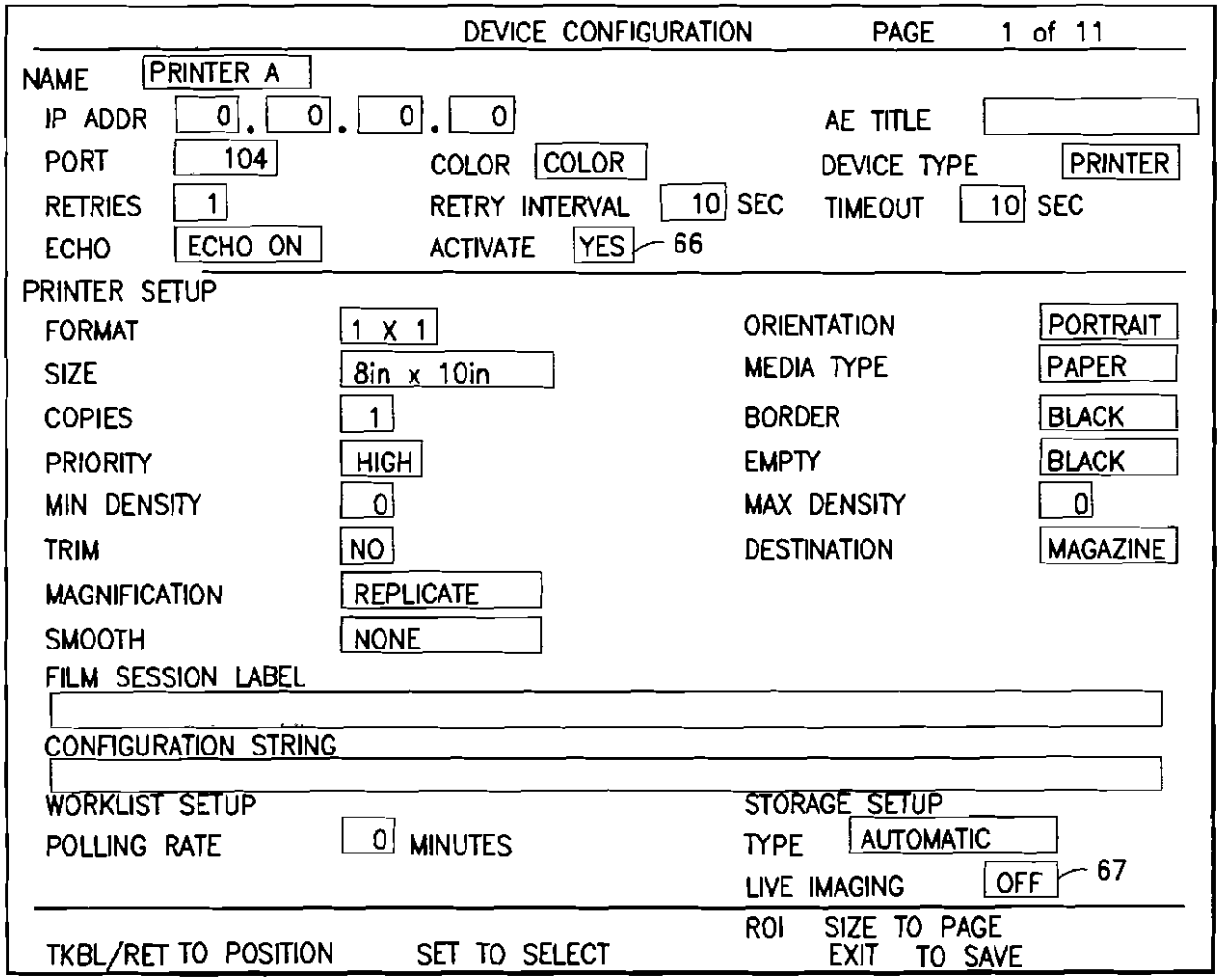

DEVICE CONFIGURATION PAGE 1 of 11
NAME PRINTER A
IP ADDR 0 . 0 . 0 . 0
AE TITLE
PORT 104
COLOR COLOR
DEVICE TYPE PRINTER
RETRIES 1
RETRY INTERVAL 10 SEC
TIMEOUT 10 SEC
ECHO ECHO ON
ACTIVATE YES
66
PRINTER SETUP
FORMAT 1 X 1
ORIENTATION PORTRAIT
SIZE 8in x 10in
MEDIA TYPE PAPER
COPIES 1
BORDER BLACK
PRIORITY HIGH
EMPTY BLACK
MIN DENSITY 0
MAX DENSITY 0
TRIM NO
DESTINATION MAGAZINE
MAGNIFICATION REPLICATE
SMOOTH NONE
FILM SESSION LABEL
CONFIGURATION STRING
WORKLIST SETUP
POLLING RATE 0 MINUTES
STORAGE SETUP
TYPE AUTOMATIC
LIVE IMAGING OFF
67
TKBL/RET TO POSITION
SET TO SELECT
ROI SIZE TO PAGE
EXIT TO SAVE

FIG.5

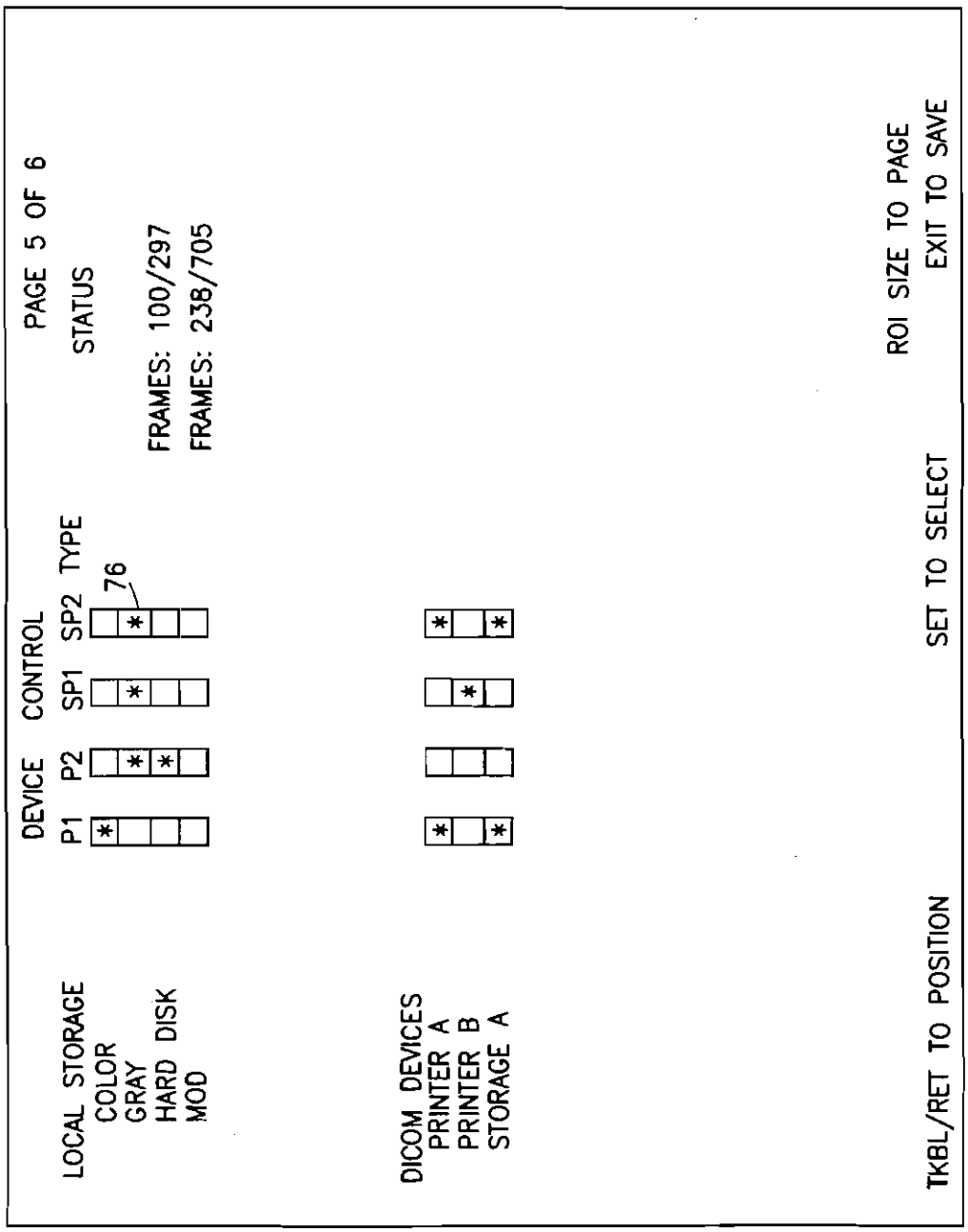

PAGE 5 OF 6
STATUS
FRAMES: 100/297
FRAMES: 238/705
DEVICE CONTROL
P1 P2 SP1 SP2 TYPE
76
LOCAL STORAGE
COLOR
GRAY
HARD DISK
MOD
DICOM DEVICES
PRINTER A
PRINTER B
STORAGE A
ROI SIZE TO PAGE
EXIT TO SAVE
SET TO SELECT
TKBL/RET TO POSITION

FIG.6

METHOD AND APPARATUS FOR SENDING ULTRASOUND IMAGE DATA TO REMOTELY LOCATED DEVICE

FIELD OF THE INVENTION

This invention generally relates to imaging systems used in medical diagnostics. In particular, the invention relates to the transfer of digital images from an ultrasound imaging system over a network to remote devices for archiving and/or printing.

BACKGROUND OF THE INVENTION

Conventional ultrasound imagers create two-dimensional images of biological tissue by scanning a focused ultrasound beam in a scan plane and for each transmitted beam, detecting the ultrasound wave energy returned along a respective scan line in the scan plane. A single scan line (or small localized group of scan lines) is acquired by transmitting focused ultrasound energy at a point, and then receiving the reflected energy over time. The focused transmit energy is referred to as a transmit beam. During the time after transmit, one or more receive beamformers coherently sum the energy received by each channel, with dynamically changing phase rotation or delays, to produce peak sensitivity along the desired scan lines at ranges proportional to the elapsed time. The resulting focused sensitivity pattern is referred to as a receive beam. A scan line's resolution is a result of the directivity of the associated transmit and receive beam pair.

A B-mode ultrasound image is composed of multiple image scan lines. The brightness of a pixel on the display screen is based on the intensity of the echo returned from the biological tissue being scanned. The outputs of the receive beamformer channels are coherently summed to form a respective pixel intensity value for each sample volume in the object region or volume of interest. These pixel intensity values are log-compressed, scan-converted and then displayed as a B-mode image of the anatomy being scanned.

If the ultrasound probe is swept over an area of body, a succession of image frames (corresponding to spaced slices intersecting the body being examined) can be displayed on the monitor. In one type of ultrasound imaging system, a long sequence of the most recent images are stored and continuously updated automatically in a cine memory on a first-in, first-out basis. The cine memory is like a circular image buffer that runs in the background, capturing image data that is displayed in real time to the user. The cine memory acts as a buffer for transfer of images to digital archival devices via the host computer. When the user freezes the system (by operation of an appropriate device on an operator interface), the user has the capability to view image data previously captured in cine memory. The image loop stored in cine memory can be reviewed on the display monitor via trackball control incorporated in the operator interface, and a section of the image loop can be selected for hard disk storage.

If the transducer probe was moving during image acquisition, the succession of image frames stored in cine memory form a three-dimensional data volume of image information. This data volume can be used by the system computer to project a three-dimensional view of the area of interest. This projected image can be returned to memory and then displayed on the monitor. Any acquired or projected image can be stored internally on the system hard disk or on a magneto-optical disk (MOD) inserted in a disk drive.

In addition to storing images internally, modern ultrasound imaging systems need to be able to transfer images to various types of remote devices via a communications network. To successfully transfer images, the relevant networking features of the ultrasound imager must be compatible with the networking features of the destination remote device. In particular, the ultrasound imager must place the data to be transferred in a format which can be handled by the destination remote device. An attempt to accomplish the foregoing is the adoption of the DICOM (Digital Imaging and Communications in Medicine) standards, which specify the conformance requirements for the relevant networking features. The DICOM standards are intended for use in communicating medical digital images among printers, workstations, acquisition modules (such as an ultrasound imaging system) and file servers. The acquisition module is programmed to transfer data in a format which complies with the DICOM standards, while the receiving device is programmed to receive data which has been formatted in compliance with those same DICOM standards.

DICOM involves more than digital image transfer. DICOM functionality includes the following Service Classes: archive/transfer images: store (across network); archive/interchange images: media storage; query for information and retrieve images; make image hard copies: print management; patient, study and results management; radiology information system modality: worklist management; and test connectivity: verification. A fundamental concept employed in DICOM is "Services on Objects". One example of an "Object" is an ultrasound image. Two examples of a "Service" are the "Store" and "Query/Retrieve" functions. In DICOM, methods of operating on information objects are referred to as "Service Object Pair Classes" (SOP Classes). Examples of SOP Classes are "Store an ultrasound image", "Print an ultrasound image", "Find which studies there are for a certain patient", "Retrieve all studies of a certain patient" and "Retrieve a worklist". Unique Identifiers (UIDs) are defined for all SOP Classes. UIDs are also given to all studies, series and images. These UIDs are, for instance, used for retrieval. In the DICOM vernacular, a patient has a study which comprises a study component, e.g., examination using a particular modality. Images acquired in sequence in the course of a study on a patient form a series of objects.

The DICOM system is based on the client/server concept. The device which uses a service (on objects) is the client device, while the device which provides the service is the server device. The client device is referred to as a Service Class User (SCU), while the server device is referred to as a Service Class Provider (SCP). The SCU sends a Service Request to the SCP over a local area network (LAN). The SCP sends back a response to the SCU over the same LAN. If the response is affirmative and a communications syntax is agreed upon, an association between the SCU and the SCP is opened and data can be transferred between the two devices. In the DICOM system a device is not limited to one role: it can be both SCU and SCP at different times.

The DICOM system is designed to facilitate the communication of digital images of different types, e.g., X-ray, computerized tomography, magnetic resonance and ultrasound imaging. In an ultrasound imager having conventional DICOM capability, three local real-world activities occur: Image Send, Image Print and Remote Verification. Image Send and Image Print can be done in either automatic or manual mode. Verification of remote DICOM devices configured on the ultrasound imager is performed when the imager is powered up or when requested by the system operator.

All DICOM activities are handled in a queued manner by application software running on a host computer incorpo-

rated in the imager. In one type of ultrasound imager, the user can select any image in cine memory to be sent in DICOM format via a LAN to a remote device having DICOM capability. The host computer of the ultrasound imaging system is programmed with DICOM system software which facilitates transmission of image frames from the cine memory to the remote DICOM device via the host computer hard disk and the LAN.

In the conventional ultrasound imager, Image Send can be used in automatic or manual mode, depending on the user configuration. When automatic mode is configured, console keys are used to capture the image and to store it on the hard disk. The request is queued to a DICOM queue manager (preferably implemented in software), which requests an association with the destination remote device. After the association with the remote device has been opened, the queue manager "pushes" the image to the remote device without user intervention. The transfer is done in the background while scanning or other operator activities continue. In manual mode, the captured images are archived on the hard disk or on a MOD during the exam(s). Upon completion of the exam(s) the images are tagged using an archive menu and queued to any of the network devices that have been configured on the imager. The images are sent sequentially in the background while scanning or other operator activities proceed. Image Print works much the same way as Image Send, in both automatic and manual modes, the only difference being that the destination device is a printer.

In order to accomplish image transfer, the ultrasound imaging system must know the configuration of the destination remote device prior to attempting to communicate with that device. The configuration data for the destination remote device is typically inputted to the ultrasound imager during software installation by a field engineer, although the DICOM network can be configured at any time. When the imager receives an instruction to transmit data to a particular remote device from the system operator, the imager software converts the image data to be transferred into the DICOM format required by the destination remote device, based on the configuration data for that device stored in system memory. The imager also sends a request over the network to the destination remote device to open an association, i.e., to connect the imager to the destination remote device. If the remote device responds in the affirmative, the imager and remote device then agree on which SOP Class is to be used and which device will act as the server and which as the client. The ultrasound imager also selects the appropriate encoding syntax from those accepted by the remote device. Other communication parameters are also negotiated.

After the DICOM communications protocol has been settled, the association is opened and the imager attempts to send the DICOM-formatted image file (object) to the remote device via the network. The transfer is done in the background while scanning or other operator activities continue. If the remote device is a storage device, each image file is transferred singly in response to a Send request inputted by the operator. The conventional imager with DICOM capability will open an association with a storage device in response to each "send to a storage device" instruction. If a transfer is successful, the association for that transfer is immediately closed. If the remote device is a printer configured to print multi-image film, then a number of images are accumulated to make up a multi-image film and an association is opened in response to a Send instruction when a number of images sufficient to fill the multi-image film have been accumulated. After the full film session of images has been transmitted, the association between the imager and printer is closed.

If the destination remote device sends back a message indicating successful receipt of the transmitted data, the DICOM-formatted image file can be deleted from the imager memory. Alternatively, the system operator can instruct the imager to retain the DICOM-formatted image file on the imager hard disk or to store it on a MOD inserted in the imager.

The remote device to which the ultrasound imager sends data can be a printer, a storage device or other device. If the operator interface of the imager has only one configurable Print/Store button, then that button will be configured to initiate data transfer to the destination remote device. The configuration data for the remote device will indicate the type of device to the imager and then the imager will format the data being transferred accordingly. If the operator interface has multiple Print/Store buttons, then each button can be configured to initiate data transfer to a respective remote device. Data transfer to any one of those configured remote devices can then be initiated by pressing the appropriate Print/Store button.

In addition to the digitized image (i.e., pixel data), the DICOM object transferred from the ultrasound imager also includes attribute information. For example, the attribute information may include patient attributes (e.g., patient name and patient identification number), study attributes (e.g., accession number and study date), series attributes (e.g., modality type and series date), and image attributes (e.g., image type and numbers of rows and columns). Each attribute has a name, a value representation and a tag. A tag is a number unique to the attribute. The value representation defines what type of value the attribute can have (e.g., a 64-character string, binary data, etc.).

In accordance with DICOM standards, there are three types of attributes. Type 1 comprises attributes which are mandatory and must always be present with a value; Type 2 comprises attributes which are mandatory but are allowed to be empty; and Type 3 comprises attributes which are optional and are also allowed to be empty. An incompatibility between two devices may arise, for example, if the receiving device requires that a Type 3 attribute be transmitted while the sending device does not include that attribute in its transmission. As a result, even if both devices are configured in accordance with current DICOM standards, the data transfer cannot occur. Thus, even mutual conformance to DICOM standards does not guarantee that two devices can be compatibly connected to each other.

In accordance with a further aspect of the DICOM system as currently implemented, an ultrasound imaging system can retrieve a worklist from a Radiology Information System (RIS) at a hospital via the LAN. The retrieved worklist may, e.g., comprise all patients to be examined on a particular day using that particular ultrasound imager. The worklist includes the following information for each patient: name, identification number, sex, birth date, accession number, study data, etc. The information retrieval is initiated by the ultrasound imager. In response to this query, the RIS transmits the worklist to the ultrasound imager, which stores it in memory. This worklist is then available for viewing by the sonographer. The patient currently being examined can be selected from the worklist.

In order to protect against image data loss due to a failed attempt to send that image data from the imager to a remote device on the network, the user must also store that image data in the local storage device, e.g., the computer hard drive. These images stored in the hard drive must be manually removed at the end of the day or when the hard

drive is full. This procedure has the disadvantages that the wrong images could be accidentally deleted; sorting through the images is difficult and prone to user error, which could result in the wrong images being printed; and more time between patient exams is required in order to perform manual image cleanup. In addition, if the imager's primary storage system or printer has a failure that cannot be corrected immediately and if the imager is implemented in such a way that the image data for the failed data transfer is lost, then the result is that the patient being examined must be rescheduled and re-scanned.

Because the DICOM capability is implemented in software, these features of the ultrasound imaging system can be readily upgraded. One goal of such upgrades is to increase the efficiency of the system operator by making the system simpler to operate, e.g., by requiring fewer manipulations to activate a particular operation. Another goal of system upgrades is to increase the ability of the imager to connect rapidly, efficiently and reliably to remote devices on the network, i.e., to increase connectivity.

SUMMARY OF THE INVENTION

The invention disclosed herein relates generally to imaging systems which acquire multiple frames of images in succession in the course of a patient examination. In particular, the invention relates to ultrasound imaging systems capable of transferring images to remotely located devices via a DICOM network. Although the preferred embodiment of the invention communicates with remote devices using the DICOM standard, the invention has application with any digital image communications standard or protocol.

In accordance with one aspect of the invention, a computerized ultrasound imager is programmed with software that provides a "Live Imaging" mode, which can be activated by clicking on a virtual representation of a "Live Imaging" toggle switch displayed on a menu. "Live Imaging" refers to the ability to keep a network association (between the imager and a remote device) open throughout the course of an examination of a patient, i.e., as images are acquired. This feature allows more efficient image transfer because the association need not be opened and closed for every image sent to a remote device, thereby reducing transfer time on the network. Each time the operator presses a Print/Store button configured to a storage device, the frozen image will be automatically sent to the remote device via the open connection. Each time the operator presses a Print/Store button configured to a printing device which prints multi-image film sessions, the frozen images are accumulated until the film session is full. The full film session is transferred to the printing device automatically upon acquisition of the last image needed to fill the film session, without the need for input by the operator of a further command. After the full film session of images has been transmitted, the association between the imager and printer is held open.

In accordance with a further aspect of the invention, the "Live Imaging" association is kept open until the system operator presses an "End Exam" button on the keyboard. Depression of the "End Exam" button closes all open associations between the imager and remote devices. In the case where the remote device is a printer configured to receive multi-image film sessions, pressing the "End Exam" button also forces the transfer of any partially filled film session from the imager to the printer for printing. The response to depression of the "End Exam" button on the keyboard is preferably implemented in software.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing a conventional ultrasound imaging system of the type which can be programmed to have DICOM capability.

FIG. **2** is a block diagram showing a typical DICOM network.

FIG. **3** is a block diagram generally depicting the hardware and software of an ultrasound imaging system in accordance with the preferred embodiment of the present invention.

FIG. **4** is a flowchart showing the steps involved in the method according to the preferred embodiment of the invention.

FIG. **5** is a schematic reproducing a "Device Configuration" menu which can be called up on the display monitor during configuration of the imaging system in accordance with the preferred embodiment of the invention.

FIG. **6** is a schematic reproducing a "Device Control" menu which can be used to configure the Print/Store buttons on the operator interface in accordance with the preferred embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows a conventional computerized ultrasound imaging system which can be programmed to communicate with remote devices over a network in conformance with the DICOM standard. The type of imaging system depicted in FIG. **1** create two-dimensional B-mode images of tissue in which the brightness of a pixel is based on the intensity of the echo return. The basic signal processing chain is as follows.

An ultrasound transducer array **2** is activated to by a transmitter in a beamformer **4** to transmit an acoustic burst which is focused at a point along a scan line. The return RF signals are detected by the transducer elements and then dynamically focused to form a receive beam by a receiver in the beamformer **4**. The receive beamformer output data (I/Q or RF) for each scan line is passed through a B-mode processing chain **6**, which preferably includes demodulation, filtering, envelope detection, logarithmic compression and edge enhancement.

Depending on the scan geometry, up to a few hundred receive vectors may be used to form a single acoustic image frame. To smooth the temporal transition from one acoustic frame to the next, some acoustic frame averaging **8** may be performed before scan conversion. In general, the log-compressed display data is converted by the scan converter **10** into X-Y format for video display. On some systems, frame averaging may be performed on the X-Y data (indicated by dashed block **12**) rather than the acoustic frames before scan conversion, and sometimes duplicate video frames may be inserted between acoustic frames in order to achieve a given video display frame rate. The scan-converted frames are passed to a video processor **14**, which maps the video data using a gray-scale mapping. The gray-scaled image frames are then sent to a video monitor **18** for display.

System control is centered in a host computer **20**, which accepts operator inputs through an operator interface **22** and in turn controls the various subsystems. (In FIG. **1**, only the image data transfer paths are depicted.) The operator interface comprises a keyboard, a trackball, a multiplicity of pushbuttons, and other input devices such as sliding and rotary knobs.

During imaging, a long sequence of the most recent images are stored and continuously updated automatically in a cine memory **16**. Some systems are designed to save the R-θ acoustic images (this data path is indicated by the dashed line in FIG. **1**), while other systems store the X-Y video images. The image loop stored in cine memory **16** can be reviewed via trackball control, and a section of the image loop can be selected for hard disk storage.

For an ultrasound imaging system which has been configured with a free-hand three-dimensional imaging capability, the selected image sequence stored in cine memory **16** is transferred to the host computer **20** for three-dimensional reconstruction. The result is written back into another portion of the cine memory, from where it is sent to the display system **18** via video processor **14**.

FIG. **2** generally depicts a simplified DICOM network having an ultrasound scanner **24**, a RIS **25**, N storage devices **26**, and M printing devices **28**, all connected to a LAN **30**. It will be readily appreciated that this diagram represents a simplified example of a DICOM network and that an actual DICOM network in the real world will have many more devices connected to the LAN, including modalities other than ultrasound imaging systems. The present invention is incorporated in an ultrasound imager (scanner) having the built-in capability to communicate with any one or more of the devices **25**, **26** and **28** in conformance with the DICOM requirements.

A portion of such an ultrasound imager is generally depicted in FIG. **3**. At the outset it should be appreciated that all of the blocks depicted in FIG. **3**, with the exceptions of the cine memory **16**, the display monitor **18** and the operator interface **22**, are preferably incorporated in the host computer (depicted in FIG. **1** as block **20**). It should be further appreciated that blocks **32**, **34**, **37–40** and **42** in FIG. **3** are preferably implemented as software.

In the system depicted in FIG. **3**, commands inputted via the operator interface **22** are detected and processed by a control platform **32**. In return, the control platform will provide signals to the operator interface which activate various visual indicators on the operator interface to indicate the status of various functions. In response to manipulation of the appropriate key or appropriate set of keys by the operator, the DICOM presets manager **39** will display a "Device Configuration" menu (shown in FIG. **5**) on the display monitor **18**. The operator then enters configuration data for the first destination remote device (e.g., "Printer A" in FIG. **5**) via the operator interface. Depending on whether the device being configured is a printer or storage device, the Device Type field on the Device Configuration menu will be filled in with either a "Printer" or a "Storage" entry. If the device being configured is a printer which prints multi-image film sessions, then the Format field in the "Printer Setup" section on the Device Configuration menu will be filled in with numbers indicating the printing format of the multi-image printer (e.g., "3×5" in the case of Printer A). For single-image printers, the entry in Format field **65** will be "1×1". A separate page of the "Device Configuration" menu will be "filled in" for each remote device which the operator wishes to configure.

The imager shown in FIG. **3** is designed to communicate with a configured remote device only if that device has been "activated". Activation causes the DICOM presets manager **39** to configure one of a multiplicity of DICOM tasks **40** in accordance with configuration data entered into the system for the associated remote device. That particular DICOM task will thereafter remain configured for that type of remote device until reconfigured for a different device. Other DICOM tasks are configured for other remote devices.

One way of activating a remote device is to click on the Activate field **66** on the Device Configuration menu to toggle the "Activate" state on. A second click on field **66** will toggle the "Activate" state off, and so forth.

In addition, for each remote device being configured, the operator may click on the box **67** to switch the "Live Imaging" mode on. A second click on box **66** will toggle the "Live Imaging" mode off, and so forth. The following description of the structure and operation of the preferred embodiment assumes that the "Live Imaging" mode is activated and that the remote receiving device accepts images one image at a time.

Referring again to FIG. **3**, the preferred embodiment is equipped with a plurality of Print/Store buttons on the operator interface **22**. Each Print/Store button can be configured by the device control mapping manager **37** to initiate image transfer to more than one remote device, e.g., when a particular Print/Store button is pressed, the computer will send the corresponding acquired image to all activated remote devices configured for that button. The device control mapping manager is programmed to retrieve a Device Control menu, which is a virtual representation of the various configurations for the Print/Store buttons, from the hard disk **36** and send it to the display monitor **18**. An exemplary Device Control menu for an imager having the functional equivalent of four Print/Store buttons, P1, P2, SP1 and SP2, is shown in FIG. **6**. The P1 and P2 control states are respectively activated by pressing buttons P1 and P2 on the operator interface; the SP1 and SP2 control states are respectively activated by pressing buttons P1 and P2 while the Shift key is also depressed. Each of these four control states in turn can be configured so that the data of the acquired image is expressed as either color intensity values or gray-scale intensity values; so that the acquired image will be stored on the hard disk or the MOD; so that the acquired image will be transferred to one or more activated remote devices (e.g., Printers A and B and Storage A denoted in FIG. **6**); or any combination of these options. For example, the imager represented in FIG. **6** is configured as follows: a color image will be transferred to Printer A and Storage A subsequent to depression of button P1; a gray-scale image will be transferred to Printer A and Storage A subsequent to depression of button P2 and the Shift key; a gray-scale image will be stored on the hard disk subsequent to depression of button P2; and a gray-scale image will be transferred to Printer B subsequent to depression of button P1 and the Shift key. Each Print/Store button configuration can be set via the operator interface. Any one of the device control fields **76** can be set by highlighting that field using the trackball and then pressing the Set key. The particular configuration of each Print/Store button is indicated by a symbol displayed in each set device control field. For each remote device ("DICOM Device" on the Device Control menu) configured to a particular Print/Store button, pressing that button after freezing an image will cause the associated DICOM task to retrieve an image file having a copy of that image from the hard disk and convert that image file to a DICOM object compatible with the associated remote device.

In accordance with the preferred embodiment, the device control mapping manager constructs a mapping of DICOM tasks (configured for respective remote devices) to Print/Store buttons. In other words, when the operator interacts with the Device Control menu (shown in FIG. **6**) to configure a Print/Store button to a particular remote device, the

device control mapping manager then identifies the DICOM task corresponding to that remote device and includes it in the device control mapping. The device control mapping manager **37** provides the device control mapping to the archive manager **34**. When the archive manager later receives a posting from the control platform **32** that a particular Print/Store button has been pressed, the archive manager **34** will then refer to the device control mapping and determine the DICOM tasks associated with that button from the mapping. The archive manager **34** then advises the DICOM queue manager **38** which DICOM tasks **40** need to construct objects incorporating the selected image frame. The DICOM queue manager **38** then copies that image file once for each task and, if the remote devices are storage devices or single-image printers, adds a job element to the Active Queue of each task. For multi-image printers, the DICOM queue manager **38** need only add another image file name to the Image File Name field of an existing job element in the queue.

Although FIG. **3** depicts only one DICOM task, in accordance with the preferred embodiment, the imager is programmed with multiple DICOM tasks. In the preferred embodiment, one DICOM task is dedicated to worklist management and ten DICOM tasks can be configured to convert image files into either DICOM print objects or DICOM storage objects. It should be appreciated, however, that the present invention is not restricted to having ten DICOM tasks for printing and storage. In response to pressing of a Print/Store button which is configured for multiple remote devices, a corresponding multiplicity of DICOM tasks will be started substantially simultaneously. These concurrently running tasks are performed using conventional multi-tasking principles.

In accordance with the preferred embodiment, the host computer of the imager is programmed to store in memory the configuration data input via the Device Configuration menu shown in FIG. **5**. For each configured remote device which is activated, a respective DICOM task is configured by the DICOM presets manager **39** in accordance with the stored configuration data. In other words, each DICOM task is partly defined by the inputs to the corresponding page of the Device Configuration menu. In particular, each DICOM task is programmed to convert an image file into a print object for printers, if "Printer" was entered in the Device Type field (see FIG. **5**) on the Device Configuration menu, and into a storage object for storage devices, if "Storage" was entered in the Device Type field. In the case where more than one remote device is designated to receive the same image, the associated DICOM tasks will convert respective copies of that image into respective DICOM objects acceptable to the respective remote devices.

The image transfer procedure used in the preferred embodiment will be described in more detail with reference to FIG. **3**. In response to a request from the operator to archive a frozen image, the control platform **32** sends an "Image Store" instruction to the archive manager **34**. In response to the "Image Store" instruction, the archive manager retrieves the frozen image from cine memory **16** and stores it either on the hard disk **36** or on the MOD **46**, depending on the system operator's selection.

In addition, the system operator may request that the frozen image be sent to an activated remote device for printing or storage by pressing the appropriate Print/Store button. In response to a first request from the operator to transfer a frozen image to a remote device which has been configured for "Live Imaging", the control platform **32** sends an "Image Send" instruction to the archive manager **38**. The archive manager **34** retrieves the frozen image from the cine memory **16** and stores it in a file on the hard disk **36**. The file includes the image pixel data as well as certain attribute data, such as patient name, patient ID, gray-scale or color image, number of rows and columns of pixels, etc. Then the archive manager **34** notifies the DICOM queue manager **38** of the image and which remote device that image is configured to go to. Next the queue manager **38** copies the image to another location on the hard disk and gives that copied image a new file name. If the pressed Print/Store button is configured for multiple remote devices, then the queue manager **38** will store multiple copies of the frozen image in multiple files, i.e., a separate copy of the frozen image for each remote device designated as a destination for that image.

In accordance with the DICOM standard, each DICOM task is designed to convert an image file, comprising image frame data and attribute data, into a DICOM-formatted object, also comprising image frame and attribute data. That DICOM object must conform not only to the DICOM standards, but also to the attribute requirements of the remote device destined to receive that DICOM object.

Jobs which are waiting to be converted into DICOM objects by a DICOM task are queued in a so-called Active Queue. The queue is managed by a DICOM queue manager **38**. For each job, the queue manager **38** adds a separate entry in the Active Queue. In particular, each entry comprises an element having multiple fields. One of those fields lists the image file names for the images in the particular job. Each image file name serves as a pointer for retrieval from memory of the named image. Another field in the element identifies the remote device (by identifying the Task ID of the DICOM task associated with that remote device) which that stored image is destined to be sent to.

The first entry in the Active Queue is sent by the queue manager **38** to a DICOM task **40**. The DICOM task **40** is preferably software for performing the task of formatting the image identified in that first entry so that the image will be in proper DICOM format and will be acceptable to the destination remote device, also identified in the first entry.

When the DICOM task **40** receives an entry from the Active Queue, it will read the Image File Name field (i.e., the pointer), which will contain the file name of the image to be formatted and transferred to the destination remote device. The DICOM task **40** then retrieves the image from the named file on the hard disk and reformats it into the appropriate DICOM object (according to the type of remote device). For example, in addition to the pixel data for the image to be transferred, the DICOM image manager will convert attribute data into DICOM format. If the remote device is a storage device, the DICOM image manager will also attach a UID to the image.

Next the DICOM task will open a connection (association) to the destination remote device and negotiate a syntax. In particular, the DICOM task **40** sends a request via the network manager **42** and a port **44** that an association with the configured remote device be opened. If the remote device responds affirmatively and if a communications syntax is agreed upon, the association is opened.

Once the association is open and assuming that a channel on the network is available (i.e., the network is not busy), the image is sent from the imager onto the network via the network manager **40** and the port **42**. If the destination remote device sends back a message that the image transfer was successful, then the DICOM task **40** notifies the queue manager **38**. The queue manager then removes the entry for

the successfully transferred image from the Active Queue and deletes that image from the hard disk **36**. If the message from the destination remote device indicates that the image transfer was unsuccessful, then the queue manager **38** moves the entry for the successfully transferred image from the Active Queue to a Holding Queue and does not delete that image from the hard disk **36**.

In the "Live Imaging" mode, the association between the imager and the destination remote device is kept open until the "End Exam" button on the operator interface **22** is pressed. While "Live Imaging" is active and for a remote device which accept images singly (i.e., one at a time), the foregoing "Image Send" procedure will be repeated each time the operator inputs a request to transfer a frozen image to the configured remote device.

The "End Exam" is a button that is pushed by the user to indicate that the examination for the current patient has ended. The process for performing an examination and sending a selected image to a storage device is shown in FIG. **4**. At the beginning of every exam the user (sonographer or sonologist) will push the "New Patient" button. When this button is pushed, a menu will appear on the screen of the display monitor (**18** in FIG. **1**). At this time, the user enters (step **48**) information about the patient (e.g., name, patient identifier, accession number, birthdate, etc.). When data entry is completed, the user exits the menu. At this time, a DICOM Study Instance UID is created. This Study Instance UID forms the base of the SOP Instance UID which tells the receiving DICOM device (SCP) that the image received belongs to a particular patient. Every image taken by the user, after exiting the "New Patient" menu, will have the same UID.

The examination may then begin. The user will scan the patient (step **50**), as needed. The user, at any time, can freeze the image (step **52**) and take a snapshot of that image to send to a storage device (step **54**). The SOP Instance UID will direct the image to the proper patient's folder of images. Storage devices receive images one at a time. The typical method of image transfer to a storage device is as follows: the queue manager opens an association (connection) with the receiving storage device; transfer negotiations occur; the image is transferred; and the association is closed. In contrast, the imager in accordance with the preferred embodiment of the present invention can be configured to open the association once and keep it open throughout the entire exam. In this case, the association is opened upon the sending of the first image. Now, all images selected to be sent after the association has been opened, and before the "End Exam" button is pushed, will be transferred during that one association. No other associations need to be made, thereby increasing transfer efficiency.

Referring again to FIG. **4**, in response to each depression of the Print/Store button configured to the destination storage device, the DICOM task **40** will determine if the association with that storage device is open (step **56**). If not, the DICOM task **40** will open the association (step **58**), as previously described. If the association is open, then the DICOM task **40** will attempt to send the DICOM object to the storage device. If the network is busy and the DICOM object cannot be sent, the DICOM object will remain queued and succeeding images will also be queued during this time. If the network will allow the DICOM object to be sent to the destination storage device, then the DICOM object constructed by the DICOM task **40** from the image identified by the first entry on the Active Queue will be transmitted to the storage device via the DICOM network (step **60**). The queue manager **38** then determines whether the "End Exam" button has been pressed (step **62**). If it has, the queue manager instructs all DICOM tasks to close any associations (step **64**). If the "End Exam" button has not been depressed, the association will not be closed and the system operator can again scan the patient after unfreezing the image (step **61**).

The "Live Imaging" procedure differs from that described above when the receiving remote device is a printer which prints multi-image film sessions (e.g., 3×5=15 images). If this were the case, the user would normally have to take all 15 images before the imager would send the job to the printer. In the "Live Imaging" mode, the association with the remote printer will not be opened until all images of the multi-image film session have been acquired. Thereafter the association with the remote printer will be held open until the "End Exam" button is pressed. If, at the time when the "End Exam" button is pressed, an incomplete film session has been acquired (i.e., the number of image file names listed in an element in the Partial Print Queue, corresponding to a particular destination printer which prints film having N images, is less than N), then this incomplete film session will be queued for subsequent transfer on the DICOM network. When a channel on the network is available, the DICOM task for that printer will transmit the multiple images making up the incomplete film session. Consequently, in accordance with the preferred embodiment of the invention, to transfer an incomplete film session to a remote printer, the system operator need press only one button, to wit, the "End Exam" button.

While the invention has been described with reference to preferred embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A method for sending image frame data from an imaging system to remote devices, comprising the steps of:

interacting with a graphical user interface to configure said imaging system to transfer successive acquired images to a first remote device in a first format compatible with said first remote device while maintaining an open association with said first remote device throughout a series of image acquisitions;

acquiring a first frame of image data;

in response to a first manipulation of a first operator input device, constructing a first data object incorporating said first frame of image data in said first format, opening an association with said first remote device, and sending said first data object to said first remote device via a network while said association with said first remote device is open;

acquiring a second frame of image data; and

in response to a second manipulation of said first operator input device, constructing a second data object incorporating said second frame of image data in said first format, and sending said second data object to said first remote device via said network while said association with said first remote device is still open.

2. The method as recited in claim 1, further comprising the steps of:

interacting with said graphical user interface to configure said imaging system to transfer successive groups of acquired images to a second remote device in a second format compatible with said second remote device while maintaining an open association with said second remote device throughout a series of image acquisitions;

acquiring a group of first through N-th frames of image data;

after each frame acquisition of said group, manipulating a second operator input device;

in response to the first (N−1) manipulations of said second operator input device, constructing a group of first through (N−1)-th data objects incorporating said group of first through (N−1)-th frames in said second format and queuing said group of first through (N−1)-th data objects; and

in response to the N-th manipulation of said second operator input device, constructing an N-th data object incorporating the N-th frame of said group in said second format, opening an association with said second remote device, and sending said group of first through N-th data objects to said second remote device via said network while said association is open.

3. The method as recited in claim 2, further comprising the steps of:

acquiring at least an (N+1)-th frame of image data;

after said (N+1)-th frame acquisition, manipulating said second operator input device;

in response to the (N+1)-th manipulation of said second operator input device, constructing an (N+1)-th data object incorporating the (N+1)-th frame in said second format and queuing said (N+1)-th data object; and

in response to manipulation of a third operator input device, sending said (N+1)-th data object to said second remote device via said network while said association is open and then closing said associations with first and second remote devices.

4. The method as recited in claim 1, further comprising the steps of:

interacting with said graphical user interface to configure said imaging system to transfer successive acquired images to a second remote device in a second format compatible with said second remote device while maintaining an open association with said second remote device throughout a series of image acquisitions;

acquiring a third frame of image data;

in response to a first manipulation of a second operator input device, constructing a third data object incorporating said third frame of image data in said second format, opening an association with said second remote device, and sending said third data object to said second remote device via a network while said association with said second remote device is open;

acquiring a fourth frame of image data; and

in response to a second manipulation of said second operator input device, constructing a fourth data object incorporating said fourth frame of image data in said second format, and sending said fourth data object to said second remote device via said network while said association with said second remote device is still open.

5. The method as recited in claim 4, further comprising the step of, in response to manipulation of a third operator input device, closing said associations with said first and second remote devices.

6. The method as recited in claim 4, wherein said steps of constructing first and third data objects are performed by first and second object-constructing tasks respectively, further comprising the step of constructing a device control mapping which maps said first and second object-constructing tasks to said first and second operator input devices respectively.

7. The method as recited in claim 1, wherein said interacting step comprises the step of clicking a virtual toggle switch on said graphical user interface to change from a first state to a second state, said first state enabling a first imaging mode wherein an association with said first remote device is not maintained open during successive image acquisitions, and said second state enabling a second imaging mode wherein an association with said first remote device is maintained open during successive image acquisitions.

8. A method for sending image frame data from an imaging system to a remote printer, comprising the steps of:

interacting with a graphical user interface to configure said imaging system to transfer successive groups of acquired images to said remote printer in a format compatible with said remote printer while maintaining an open association with said remote printer throughout a series of image acquisitions;

acquiring first through N-th frames of image data;

after each frame acquisition, manipulating a first operator input device;

in response to the first (N−1) manipulations of said first operator input device, constructing first through (N−1)-th data objects incorporating the first through (N−1)-th frames in said format and queuing said first through (N−1)-th data objects; and

in response to the N-th manipulation of said first operator input device, constructing an N-th data object incorporating the N-th frame in said format, opening an association with said remote printer, and sending said first through N-th data objects to said remote printer via said network while said association is open.

9. The method as recited in claim 8, further comprising the steps of:

acquiring at least an (N+1)-th frame of image data;

after said (N+1)-th frame acquisition, manipulating said first operator input device;

in response to the (N+1)-th manipulation of said first operator input device, constructing an (N+1)-th data object incorporating the (N+1)-th frame in said format and queuing said (N+1)-th data object; and

in response to manipulation of a second operator input device, sending said (N+1)-th data object to said remote printer via said network while said association is open and then closing said association with said remote printer.

10. An imaging system capable of sending image frame data to a remote device via a network, comprising:

a networking port for communicating with a network;

a graphical user interface for configuring said imaging system to transfer successive acquired images to a remote device on said network in a format compatible with said remote device while maintaining an open association with said remote device via said network throughout a series of image acquisitions;

an operator interface comprising first and second operator input devices;

means for acquiring first and second frames of image data;

an object constructing task for constructing first and second data objects respectively incorporating said first and second frames of image data in said format; and

means for transferring said first and second data objects to said networking port for transmission to said remote device,

wherein in response to a first manipulation of said first operator input device, said object constructing task constructs said first data object, opens an association with said remote device via said network, and sends said first data object to said remote device via a network while said association with said remote device is open, and in response to a second manipulation of said first operator input device, said object constructing task constructs said second data object and sends said second data object to said remote device via said network while said association with said remote device is still open.

11. The system as recited in claim 10, wherein said association with said remote device is closed in response to manipulation of said second input device.

12. An imaging system capable of sending image frame data to remote devices via a network, comprising:

a networking port for communicating with a network;

a graphical user interface comprising a first menu for configuring said imaging system to transfer successive acquired images to a first remote device on said network in a first format compatible with said first remote device while maintaining an open association with said first remote device via said network throughout a series of image acquisitions, and a second menu for configuring said imaging system to transfer successive acquired images to a second remote device on said network in a second format compatible with said second remote device while maintaining an open association with said second remote device via said network throughout a series of image acquisitions;

au operator interface comprising first, second and third operator input devices;

means for acquiring first through fourth frames of image data;

a first object constructing task for constructing first and second data objects respectively incorporating said first and second frames of image data in said first format;

a second object constructing task for constructing third and fourth data objects respectively incorporating said third and fourth frames of image data in said second format; and

means for transferring said first through fourth data objects to said networking port,

wherein in response to a first manipulation of said first operator input device, said first object constructing task constructs said first data object, opens an association with said first remote device via said network, and sends said first data object to said first remote device via a network while said association with said first remote device is open, and in response to a second manipulation of said first operator input device, said first object constructing task constructs said second data object and sends said second data object to said first remote device via said network while said association with said first remote device is still open, and in response to a first manipulation of said second operator input device, said second object constructing task constructs said third data object, opens an association with said second remote device via said network, and sends said third data object to said second remote device via a network while said association with said second remote device is open, and in response to a second manipulation of said second operator input device, said second object constructing task constructs said fourth data object and sends said fourth data object to said second remote device via said network while said association with said second remote device is still open.

13. The system as recited in claim 12, wherein said associations with said first and second remote devices are closed in response to manipulation of said third input device.

14. An imaging system capable of sending image frame data to a remote printer via a network, comprising:

a networking port for communicating with a network;

a graphical user interface for configuring said imaging system to transfer acquired images to a remote printer on said network in a format compatible with said remote printer while maintaining an open association with said remote printer via said network;

an operator interface comprising first and second operator input devices;

means for acquiring first through N-th frames of image data;

an object constructing task for constructing first through N-th data objects respectively incorporating said first through N-th frames of image data in said format; and

means for transferring said first through N-th data objects to said networking port for transmission to said remote printer,

wherein in response to first through (N−1)-th manipulations of said first operator input device, said object constructing task constructs first through (N−1)-th data objects incorporating the first through (N−1)-th frames in said format and queues said first through (N−1)-th data objects, and in response to the N-th manipulation of said first operator input device, said object constructing task constructs an N-th data object incorporating the N-th frame in said format, opens an association with said remote printer via said network, and sends said first through N-th data objects to said remote printer via said network while said association is open.

15. The system as recited in claim 14, further comprising means for acquiring at least an (N+1)-th frame of image data, wherein in response to an (N+1)-th manipulation of said first operator input device, said object constructing task constructs an (N+1)-th data object incorporating the (N+1)-th frame in said format and queuing said (N+1)-th data object, and in response to manipulation of said second operator input device, sends said (N+1)-th data object to said remote printer via said network while said association is open and then closes said association with said remote printer.

* * * * *

EXHIBIT E

US006418225B2

(12) **United States Patent**
Stratton et al.

(10) **Patent No.: US 6,418,225 B2**
(45) **Date of Patent: Jul. 9, 2002**

(54) **METHOD AND APPARATUS FOR FEATURE CONFIGURATION IN REMOTELY LOCATED ULTRASOUND IMAGING SYSTEM**

(75) Inventors: **Gregory C. Stratton**, Wauwatosa; **Charles Cameron Brackett**, Waukesha; **Chandler A. Johnson**, Oconomowoc, all of WI (US)

(73) Assignee: **General Electric Company**, Waukesha, WI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/775,519**

(22) Filed: **Feb. 5, 2001**

Related U.S. Application Data

(62) Division of application No. 09/065,171, filed on Apr. 23, 1998, now Pat. No. 6,246,770.

(51) **Int. Cl.**[7] **H04L 9/08**; G06F 9/00

(52) **U.S. Cl.** **380/281**; 713/182; 713/183; 713/189; 713/160

(58) **Field of Search** 713/182, 183, 713/200; 380/281

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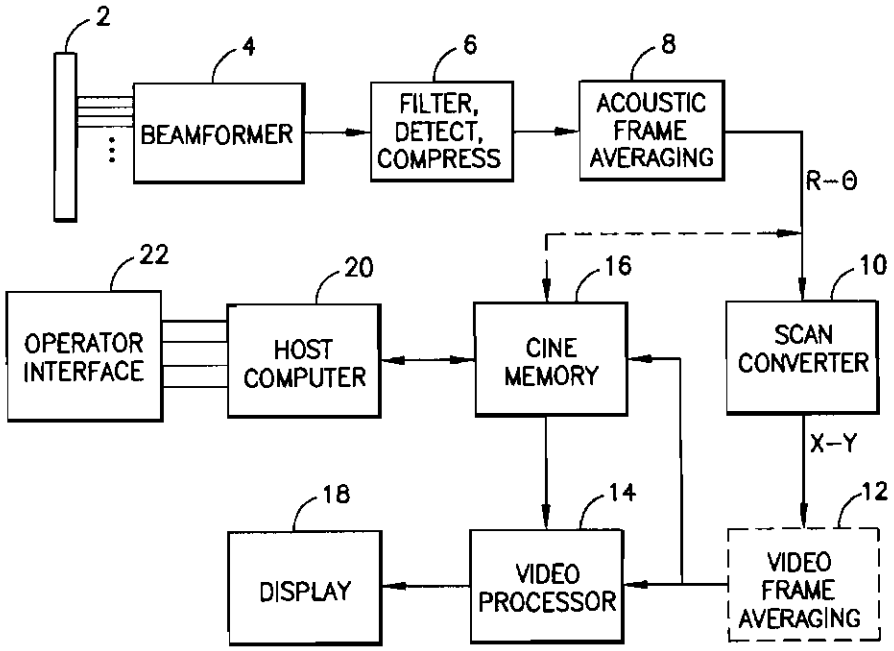
Primary Examiner—Gilberto Barron
Assistant Examiner—Todd M. Jack
(74) *Attorney, Agent, or Firm*—Ostrager Chong & Flaherty LLP

(57) **ABSTRACT**

A method and apparatus for configuring an ultrasound imaging system at a remote location by obtaining an encrypted feature key from a central location (e.g., via telephone) and then inputting that feature key into the ultrasound imaging system using an operator interface (e.g., a keyboard). To validate the feature key, the ultrasound imaging system decrypts the encrypted data and then compares the decrypted data to validation data pre-stored in the system. If the decrypted data matches the validation data, then the optional feature identified by the feature key will be enabled each time the system is booted or initialized. Optionally, an expiration date can be associated with the activated option, after which date the feature will be disabled when the system is initialized. Similarly, an activated optional feature can be disabled at a remote location by the input of an encrypted key obtained from a central location.

31 Claims, 3 Drawing Sheets



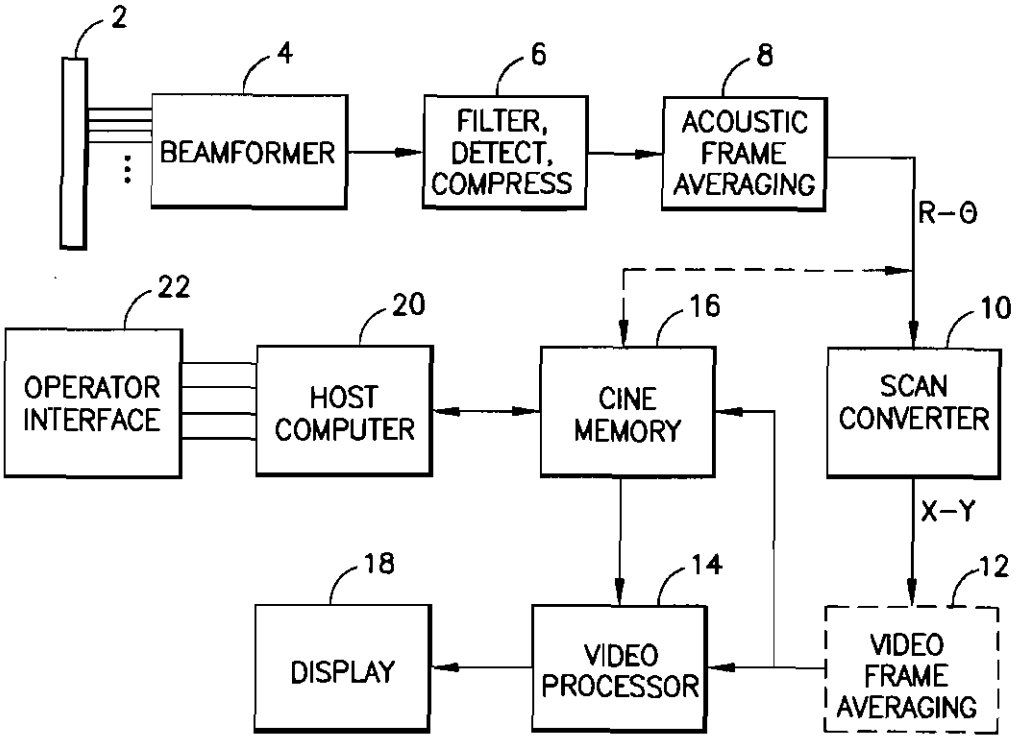

2
4
6
8
BEAMFORMER
FILTER, DETECT, COMPRESS
ACOUSTIC FRAME AVERAGING
R–θ
22
20
16
10
OPERATOR INTERFACE
HOST COMPUTER
CINE MEMORY
SCAN CONVERTER
X–Y
18
14
12
DISPLAY
VIDEO PROCESSOR
VIDEO FRAME AVERAGING

FIG. 1

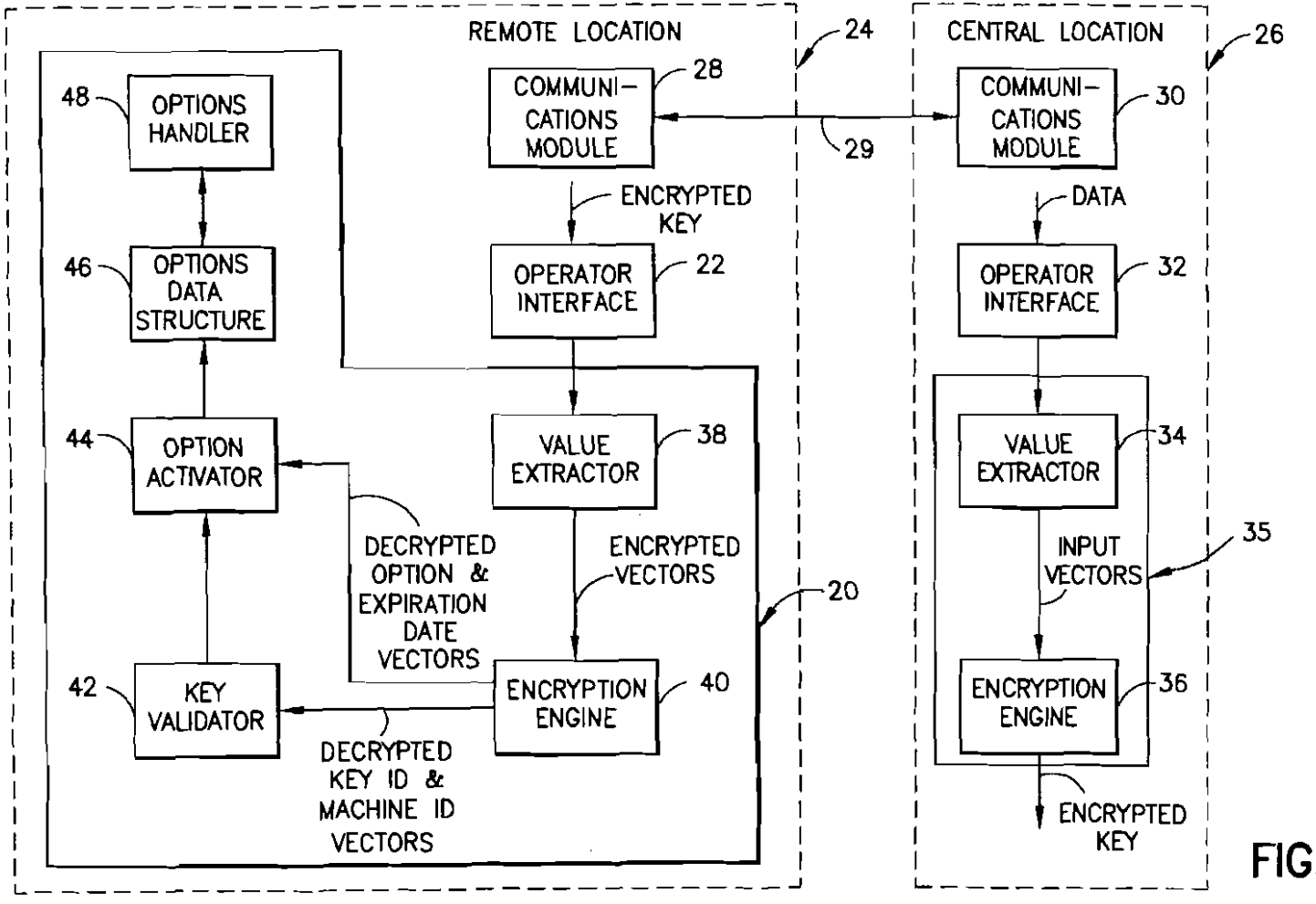

REMOTE LOCATION
24
CENTRAL LOCATION
26
48
OPTIONS HANDLER
COMMUNI-CATIONS MODULE
28
COMMUNI-CATIONS MODULE
30
29
ENCRYPTED KEY
DATA
46
OPTIONS DATA STRUCTURE
OPERATOR INTERFACE
22
OPERATOR INTERFACE
32
44
OPTION ACTIVATOR
VALUE EXTRACTOR
38
VALUE EXTRACTOR
34
DECRYPTED OPTION & EXPIRATION DATE VECTORS
ENCRYPTED VECTORS
INPUT VECTORS
35
20
42
KEY VALIDATOR
ENCRYPTION ENGINE
40
ENCRYPTION ENGINE
36
DECRYPTED KEY ID & MACHINE ID VECTORS
ENCRYPTED KEY

FIG.2

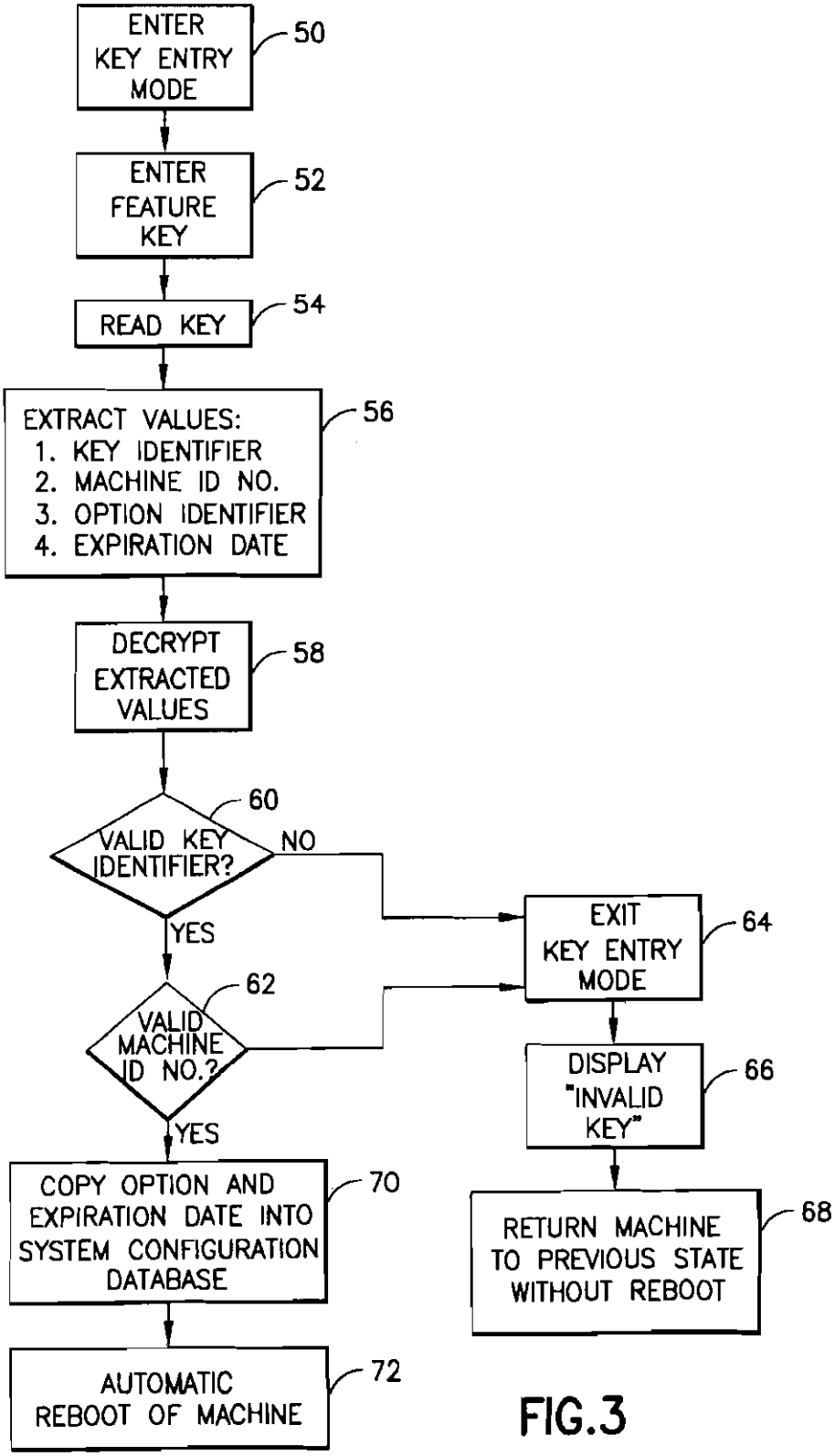

ENTER KEY ENTRY MODE
50
ENTER FEATURE KEY
52
READ KEY
54
EXTRACT VALUES:
1. KEY IDENTIFIER
2. MACHINE ID NO.
3. OPTION IDENTIFIER
4. EXPIRATION DATE
56
DECRYPT EXTRACTED VALUES
58
VALID KEY IDENTIFIER?
60
NO
YES
VALID MACHINE ID NO.?
62
YES
EXIT KEY ENTRY MODE
64
DISPLAY "INVALID KEY"
66
RETURN MACHINE TO PREVIOUS STATE WITHOUT REBOOT
68
COPY OPTION AND EXPIRATION DATE INTO SYSTEM CONFIGURATION DATABASE
70
AUTOMATIC REBOOT OF MACHINE
72

FIG.3

METHOD AND APPARATUS FOR FEATURE CONFIGURATION IN REMOTELY LOCATED ULTRASOUND IMAGING SYSTEM

RELATED APPLICATION

This is a divisional of and claims priority from U.S. patent application Ser. No. 09/065,171 filed on Apr. 23, 1998. Now U.S. Pat. No. 6,246,770 issue date Jun. 12, 2001.

FIELD OF THE INVENTION

This invention generally relates to systems for ultrasound imaging of the human anatomy for the purpose of medical diagnosis. In particular, the invention relates to a method for configuring a remotely located ultrasound imaging system to add or delete features.

BACKGROUND OF THE INVENTION

Conventional ultrasound scanners create two-dimensional B-mode images of tissue in which the brightness of a pixel is based on the intensity of the echo return. The basic signal processing chain in the conventional B mode is depicted in FIG. **1**. An ultrasound transducer array **2** is activated to transmit an acoustic burst along a scan line. The return RF signals are detected by the transducer elements and then formed into a receive beam by the beamformer **4**. The beamformer output data (I/Q or RF) for each scan line is passed through a B-mode processing chain **6** which includes demodulation, equalization filtering, envelope detection and logarithmic compression. Depending on the scan geometry, up to a few hundred vectors may be used to form a single acoustic image frame. To smooth the temporal transition from one acoustic frame to the next, some acoustic frame averaging **8** may be performed before scan conversion.

In general, the log-compressed display data is converted by the scan converter **10** into X-Y format for video display. On some systems, frame averaging may be performed on the X-Y data (indicated by dashed block **12**) rather than the acoustic frames before scan conversion, and sometimes duplicate video frames may be inserted between acoustic frames in order to achieve a given video display frame rate. The scan-converted frames are passed to a video processor **14**, which maps the video data to a gray-scale mapping for video display. The gray-scale image frames are then sent to a video monitor **18** for display.

System control is centered in a host computer **20**, which accepts operator inputs through an operator interface **22** (e.g., a keyboard) and in turn controls the various subsystems. (In FIG. **1**, only the image data transfer paths are depicted.) During B-mode imaging, a long sequence of the most recent images are stored and continuously updated automatically in a cine memory **16**. Some systems are designed to save the R-θ acoustic images (this data path is indicated by the dashed line in FIG. **1**), while other systems store the X-Y video images. The image loop stored in cine memory **16** can be reviewed via track-ball control, and a section of the image loop can be selected for hard disk storage.

For an ultrasound imaging system which has been configured with a free-hand three-dimensional imaging capability, the selected image sequence stored in cine memory **16** is transferred to the host computer **20** for three-dimensional reconstruction. The result is written back into another portion of the cine memory, from where it is sent to the display system **18** via video processor **14**.

From the standpoint of the vendor of the ultrasound imaging system, it is desirable to sell or lease systems

having built-in optional features which can be activated at a location remote from a central billing station. For example, the capability of free-hand three-dimensional imaging can be an optional feature which must be purchased from the system vendor. To ensure that the system user is charged for the use of such optional features, it is known to provide means for blocking activation of optional features unless authorization is obtained from the manufacturer. Authorization can also be given to allow for use of an optional feature free of charge for a predetermined trial period. In one conventional ultrasound system, this is accomplished by delivery of an authorized feature activation disk, which is inserted into a slot in the system. The disk has validation information and feature information stored thereon. The system compares the validation information with a unique validation standard pre-stored in the system memory. If the validation data matches the unique pre-stored standard, the feature information stored on the disk is incorporated in the system configuration database. Thereafter and until the expiration date, whenever the system is initialized, optional feature or features represented by the feature information of the disk will be enabled.

However, there is a need for a method of configuring an ultrasound imaging system at a remote location without physically transferring an authorization disk or card from the central location to the remote location. In particular, there is a need for a method of system configuration which can be carried out remotely while avoiding the delays inherent in the shipment or delivery of a disk or card from a central location.

SUMMARY OF THE INVENTION

The present invention is a method and apparatus for configuring an ultrasound imaging system at a remote location by obtaining an encrypted feature key from a central location (e.g., via telephone) and then inputting that feature key into the ultrasound imaging system using an operator interface (e.g., a keyboard). To validate the feature key, the system decrypts the encrypted data and then compares the decrypted data to validation data pre-stored in the system. If the decrypted data matches the validation data, then the optional feature identified by the feature key will be enabled each time the system is booted or initialized. Optionally, an expiration date can be associated with the activated option, after which date the feature will be disabled when the system is initialized.

In accordance with the broad scope of the invention, an activated optional feature can be disabled at a remote location by the input of an encrypted key obtained from a central location. The term "feature key" shall be used hereinafter to mean any key for activating or deactivating an optional feature.

To enable an optional feature on the ultrasound system in accordance with the preferred embodiment of the invention, an authorized service representative or other user at the remote location opens a communication link with a central location. In order to obtain a feature key for enabling the feature, the user must identify the option desired and provide the machine identification number and the option expiration date to the central location. Service personnel at the central location then run a key maker application using the given data. The key maker application employs a value extractor to organize the inputted data into vectors, and an encryption engine to transform those vectors (by multiplying each vector with a non-singular matrix) into an encrypted feature key comprising a string of numeric characters. The

dator generates a signal which enables the option activator **44**. The option activator **44** receives the decrypted option and expiration date from the encryption engine **40** and copies that data into respective fields in options data structure **46**, which forms part of the system configuration database. The ultrasound imaging system is then rebooted automatically. Upon rebooting, the options handler **48** configures the system in accordance with the new data stored in the options data structure **46**. In particular, the options handler **48** enables the feature identified by the new options datum stored in the options field. That feature will be enabled each time the system is initialized until expiration of the option on the date indicated in the expiration date field of the options data structure.

The method for configuring a remotely located ultrasound imaging system in accordance with the preferred embodiment of the invention is shown in more detail in FIG. **3**. To facilitate entry of the encrypted feature key into the system, first the user must enter a predetermined sequence of alphanumeric characters representing an enter key entry mode command (step **50**). The characters can be entered, for example, by depressing keys located either on a front panel of the system or on a modular keyboard connected to the system. A parameter routine interprets the predetermined sequence of alphanumeric characters (e.g., the sequence Δ+2) as the enter key entry mode command, placing the machine in a suspended state (i.e., the feature key entry mode). In the feature key entry mode, the next data inputted into the system will be processed as a feature key.

In the feature key entry mode, the user enters the string of numeric characters representing the encrypted feature key into the operator interface (step **52**). Optionally, as the user types in the encrypted feature key, the system can respond to each key depression with a form of acknowledgement. The end of the string of numeric characters is indicated by depressing the "Enter" on the operator interface. The inputted encrypted key is then read (step **54**) by storing the string of numeric characters in a buffer incorporated in the value extractor **38** (see FIG. **2**). The "Read Key" function is enabled when the user types in the enter key entry mode command.

The value extractor parses or extracts the values (step **56**) representing the key identifier, machine identification number, option and expiration date and then organizes those values into respective encrypted vectors. The encrypted vectors are then decrypted (step **58**) using the inverted non-singular encryption matrix, as previously described. The decrypted key identifier data is then compared with a key identifier pre-stored in the system configuration database to determine whether the feature key is valid (step **60**). If the feature key is valid, then the machine identification number, i.e., serial number, is compared with a machine identification number (also pre-stored in the system configuration database) which is unique to the system being configured (step **62**). If the machine identification number is valid, then the decrypted option and expiration date are copied into respective fields in an options data structure in the system configuration database (step **70**). The ultrasound imaging system is then rebooted automatically (step **72**).

If either the key identifier or the machine identification number is invalid (steps **60** and **62** in FIG. **3**), then the system exits the feature key entry mode (step **64**). The message "Invalid Key" is displayed on the monitor (step **66**). Then the system returns to its previous state without rebooting (step **68**).

The foregoing preferred embodiments have been disclosed for the purpose of illustration. Variations and modifications of the basic concept of the invention will be readily apparent to persons skilled in the art. In particular, it will be appreciated that the encrypted feature key can be transmitted from the central location to a remote location via a communications link different than the link used to transmit data from the remote location to the central location. In addition, although the disclosed preferred embodiments employ encrypted numeric codes, it will be appreciated that the system can be readily adapted to operate using encrypted alphabetic or alphanumeric codes. All such variations and modifications are intended to be encompassed by the claims set forth hereinafter.

What is claim is:

1. A method for configuring a computerized system at a remote location, comprising the steps of:

storing a validation identifier inside said system;

transmitting an option identifier which identifies a change in system configuration from said remote location to a central location;

encrypting said validation identifier and said option identifier at said central location;

transmitting an encrypted feature key comprising a sequence of characters from said central location to said remote location, said encrypted feature key comprising said encrypted validation identifier and said encrypted option identifier;

placing said system in a feature key entry mode;

inputting said encrypted feature key into said system by operation of a sequence of input keys corresponding to said sequence of characters of said encrypted feature key;

decrypting said encrypted feature key inside said system to form decrypted data comprising a decrypted validation identifier and a decrypted option identifier;

comparing said decrypted validation identifier with said stored validation identifier;

altering a system configuration database inside said system to reflect said change in system configuration if said decrypted validation identifier matches said stored validation identifier.

2. The method as defined in claim **1**, wherein said change in system configuration is addition of an optional feature.

3. The method as defined in claim **1**, wherein said change in system configuration is deletion of an optional feature.

4. A method for configuring a computerized system, comprising the steps of:

booting a system with an intial system configuration;

placing said system in a feature key entry mode;

inputting an encrypted feature key into said system via an operator interface, said encrypted feature key comprising an encrypted validation identifier and an encrypted option identifier;

decrypted said encrypted feature key inside said system to from decrypted date comprising a decrypted validation identifier and a decrypted option identifier;

comparing said decrypted validation identifier with a pre-stored validation identifier;

altering a system configuration database inside said system to reflect a change in system configuration identifier by said decrypted option identifier if said decrypted validation identifier matches said stored validation identifier; and

rebooting said system with said change system configuration following said altering step and before use of said system.

5. The method as defined in claim 4, wherein said change in system configuration is addition of an optional feature.

6. The method as defined in claim 4, wherein said change in system configuration is deletion of an optional feature.

7. An ultrasound imaging system comprising:

an ultrasound transmitter for transmitting ultrasound energy into a volume of ultrasound scatterers;

a signal processing chain for acquiring display data representing an image of ultrasound scatterers in said volume in accordance with a system configuration comprising enabled features, said display data being based on ultrasound energy scattered by said ultrasound scatterers;

a monitor for displaying said image in response to receipt of said display data;

a memory for storing a system configuration database representing said enabled features of said system configuration;

an operator interface comprising a plurality of keys for inputting data into said system;

means for placing said system in a feature key entry mode in response to a predetermined command input via said operator interface; and

decrypting means for outputting decrypted data in response to depression of a sequence of keys of said operator representing an encrypted feature key comprising an encrypted validation identifier and an encrypted option identifier, said decrypted data comprising a decrypted validation identifier and a decrypted option identifier;

validating means for determining if said decrypted validation identifier is valid; and

means for altering said system configuration as a function of said decrypted option identifier only if said decrypted validation identifier is valid.

8. The system as defined in claim 7, wherein said change in system configuration is addition of an optional feature.

9. The system as defined in claim 7, wherein said change in system configuration is deletion of an optional feature.

10. The system as defined in claim 7, further comprising means for storing decryption matrix precursor data and means for constructing a decryption matrix based on said decryption matrix precursor data, wherein said decrypting means perform decryption by applying said decryption matrix to vectors formed from said encrypted feature key.

11. A system comprising:

an operation interface;

memory which stores a computer booting routine, an optional computer feature, a system configuration database comprising a validation identifier and a list of computer features to be activated at during computer booting, and a computer feature activation/de-activation routine for selectively adding or deleting an identifier of said optional computer feature to or from said list of activated computer features in said system configuration database; and

a computer which executes said computer booting routine during booting, executes said computer feature activation/de-activation routine only in response to entry of a first predetermined command via said operator interface after booting, and executes said computer optional feature in response to entry of a second predetermined command via said operator interface after booting if said optional computer feature has been activated during booting,

wherein said computer feature activation/de-activation routine comprises the following steps:

decrypting a feature key entered via said operator interface to form decrypted data comprising a decrypted validation identifier and a decrypted optional computer feature identifier;

comparing said decrypted validation identifier with said stored validation identifier in said system configuration database; and

adding or deleting said decrypted optional computer feature identifier to or from said list of activated computer features in said system configuration database provided that said decrypted validation identifier matches said stored validation identifier.

12. The system as recited in claim 11, wherein said system is a scanner.

13. The system as recited in claim 12, wherein said scanner is an ultrasound imaging system.

14. The system as recited in claim 11, wherein said computer feature activation/de-activation routine further comprises the step of rebooting said computer following said adding/deleting step and before use of said system.

15. The system as recited in claim 11, wherein said decrypted data derived from said feature key further comprises a decrypted expiration date, and said adding step further comprises associating said decrypted expiration date with said decrypted optional computer feature identifier in said list of activated computer features in said system configuration database.

16. The system as recited in claim 11, wherein said computer feature activation/de-activation routine further comprises the step of constructing a decryption matrix inside said system from decryption matrix precursor data, wherein said decrypting step is carried out by applying said decryption matrix to vectors formed from said feature key.

17. The system as recited in claim 11, wherein said validation identifier comprises a system identifier which uniquely identifies said system.

18. The system as recited in claim 17, wherein said validation identifier further comprises a key identifier.

19. A method for configuring a computerized system, comprising the following steps:

booting said computerized system with a system configuration wherein only those optional computer features which are identified in a list of activated optional computer features listed in a system configuration database stored in system memory are activated;

inputting a command via an operator interface which causes said computerized system to enter a feature activation mode;

inputting an encrypted feature key into said computerized system via said operator interface while said computerized system is in said feature activation mode, said encrypted feature key comprising an encrypted validation identifier and an encrypted optional computer feature identifier, wherein said encrypted optional computer feature identifier corresponds to an optional computer feature not identified in said list of activated optional computer features;

automatically decrypting said feature key inputted via said operator interface to form decrypted data comprising a decrypted validation identifier and a decrypted optional computer feature identifier;

automatically comparing said decrypted validation identifier with a stored validation identifier in said system configuration database; and

automatically adding said decrypted optional computer feature identifier to said list of activated computer features in said system configuration database if said decrypted validation identifier matches said stored validation identifier.

20. The method as recited in claim **19**, further comprising the step of rebooting said computer with a system configuration comprising said optional computer feature following said adding step and before use of said system.

21. The method as recited in claim **19**, wherein said encrypted feature key further comprises an encrypted expiration date, said decrypted data derived from said feature key further comprises a decrypted expiration date, and said adding step further comprises associating said decrypted expiration date with said decrypted optional computer feature identifier in said list of activated computer features in said system configuration database.

22. The method as recited in claim **19**, wherein said computer feature activation routine further comprises the step of constructing a decryption matrix inside said system from decryption matrix precursor data, wherein said decrypting step is carried out by applying said decryption matrix to vectors formed from said feature key.

23. The method as recited in claim **19**, wherein said validation identifier comprises a system identifier which uniquely identifies said computerized system.

24. The method as recited in claim **23**, wherein said validation identifier further comprises a key identifier.

25. A method for configuring a computerized system, comprising the following steps:

booting said computerized system to have a system configuration wherein only those optional computer features which are identified in a list of activated optional computer features listed in a system configuration database stored in system memory are activated;

inputting a command via an operator interface which causes said computerized system to enter a feature de-activation mode;

inputting an encrypted feature key into said computerized system via said operator interface while said computerized system is in said feature de-activation mode, said encrypted feature key comprising an encrypted validation identifier and an encrypted optional computer feature identifier, wherein said encrypted optional computer feature identifier corresponds to an optional computer feature identified in said list of activated optional computer features;

automatically decrypting said feature key inputted via said operator interface to form decrypted data comprising a decrypted validation identifier and a decrypted optional computer feature identifier;

automatically comparing said decrypted validation identifier with a stored validation identifier in said system configuration database; and

automatically deleting said decrypted optional computer feature identifier from said list of activated computer features in said system configuration database if said decrypted validation identifier matches said stored validation identifier.

26. The method as recited in claim **25**, further comprising the step of rebooting said computer with a system configuration not including said optional computer feature following said deleting step and before use of said system.

27. A method for configuring a computerized system, comprising the steps of:

pre-storing an option and an activation status datum in said system, said activation status datum having a first value indicating that said option should not be activated when said system is booted;

transmitting data comprising an option identifier identifying said option and a machine identification number identifying said system from a remote location to a central location;

at said central location, receiving said data, adding a key identifier to said data, encrypting said key identifier and said data to form an encrypted feature key, and transmitting said encrypted feature key to said remote location;

inputting said encrypted feature key into said system via an operator interface;

inside said system, automatically performing the following steps:

decrypting said encrypted feature key inside said system to form decrypted data comprising said key identifier, said option identifier and said machine identification number;

validating said key identifier and said machine identification number resulting from decryption; and

changing said activation status datum from said first value to a second value if said key identifier and said machine identification number are valid, said second value indicating that said option should be activated when said system is booted.

28. A method for configuring a computerized system, comprising the steps of:

pre-storing an option and an activation status datum in said system, said activation status datum having a first value indicating that said option should be activated when said system is booted;

transmitting data comprising an option identifier identifying said option and a machine identification number identifying said system from a remote location to a central location;

at said central location, receiving said data, adding a key identifier to said data, encrypting said key identifier and said data to form an encrypted feature key, and transmitting said encrypted feature key to said remote location;

inputting said encrypted feature key into said system via an operator interface; and

inside said system, automatically performing the following steps:

decrypting said encrypted feature key to form decrypted data comprising said key identifier, said option identifier and said machine identification number;

validating said key identifier and said machine identification number resulting from decryption; and

changing said activation status datum from said first value to a second value if said key identifier and said machine identification number are valid, said second value indicating that said option should not be activated when said system is booted.

29. A system comprising:

an operator interface;

memory storing an option, an option identifier identifying said option, and an activation status datum, said activation status datum having either first or second values, said first value indicating that said option should not be activated when said system is booted and said second

value indicating that said option should be activated when said system is booted; and

a computer programmed to perform the following steps in an option activation mode:

detecting entry of an encrypted feature key via said operator interface:

decrypting said encrypted feature key to form decrypted data;

verifying that said decrypted data comprise a valid key identifier and a valid machine identification number; and

after verification, changing said activation status datum from one of said first and second values to the other of said first and second values if said decrypted data comprise said option identifier.

30. The system as recited in claim **29**, wherein said system is an ultrasound imaging system.

31. A method for changing a state of activation of an optional software feature stored in a computerized system via an operator interface, comprising the steps of:

inputting an enter feature key entry mode command; and

inputting an encrypted feature key comprising a machine identification number identifying said computerized system, an option identifier identifying said optional software feature, an expiration date on which said optional software feature should be de-activated, and a key identifier.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,418,225 B2
DATED : July 9, 2002
INVENTOR(S) : Gregory C. Stratton et al.

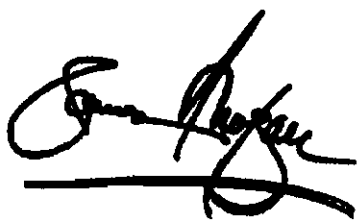
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6,
Line 48, "intial" should read -- initial --.
Line 55, "decrypted" should read -- decrypting --.
Line 56, "from" should read -- form --, and "date" should read -- data --.
Line 57, "identifier" should read -- identified --.
Line 65, "change" should read -- changed --.

Column 7,
Line 27, insert -- interface -- after "operator".
Line 53, delete "at".

Signed and Sealed this

Twenty-fifth Day of February, 2003



JAMES E. ROGAN
Director of the United States Patent and Trademark Office

EXHIBIT F

US006102859A

United States Patent [19]

Mo

[11] Patent Number: 6,102,859

[45] Date of Patent: Aug. 15, 2000

[54] **METHOD AND APPARATUS FOR AUTOMATIC TIME AND/OR LATERAL GAIN COMPENSATION IN B-MODE ULTRASOUND IMAGING**

[75] Inventor: **Larry Y. L. Mo**, Waukesha, Wis.

[73] Assignee: **General Electric Company**, Milwaukee, Wis.

[21] Appl. No.: **09/203,440**

[22] Filed: **Dec. 1, 1998**

[51] **Int. Cl.**[7] **A61B 8/00**

[52] **U.S. Cl.** **600/443**; 600/447

[58] **Field of Search** 600/437, 440, 600/441, 443, 447; 73/625–628; 128/916

[56] **References Cited**

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Primary Examiner—Marvin M. Lateef

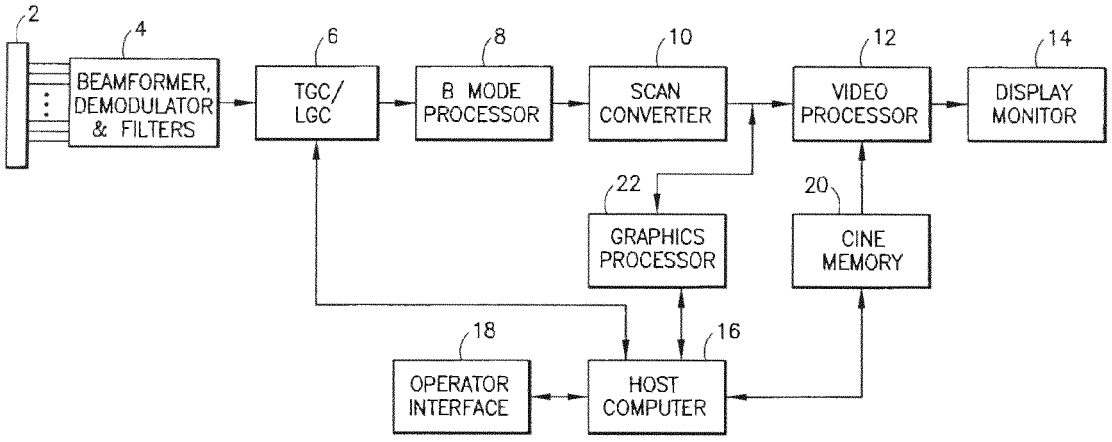
Assistant Examiner—Ali M. Imam

Attorney, Agent, or Firm—Dennis M. Flaherty; Christian G. Cabou; Phyllis Y. Price

[57] **ABSTRACT**

A method and an apparatus for automating time-gain compensation (TGC) and lateral-gain compensation (LGC) based on the B-mode image data. The automatic gain adjustments are aimed at equalizing the mean signal intensities along the axial (for TGC) and/or lateral (for LGC) direction of the image, and suppressing any lateral band (for TGC) and/or sector (for LGC) that contains mostly noise. The automatic TGC/LGC adjustment method is implemented in software on a digital scanner and uses a noise model of the entire B-mode processing chain from the beamformer through the B-mode processor to the back-end video processor.

15 Claims, 3 Drawing Sheets



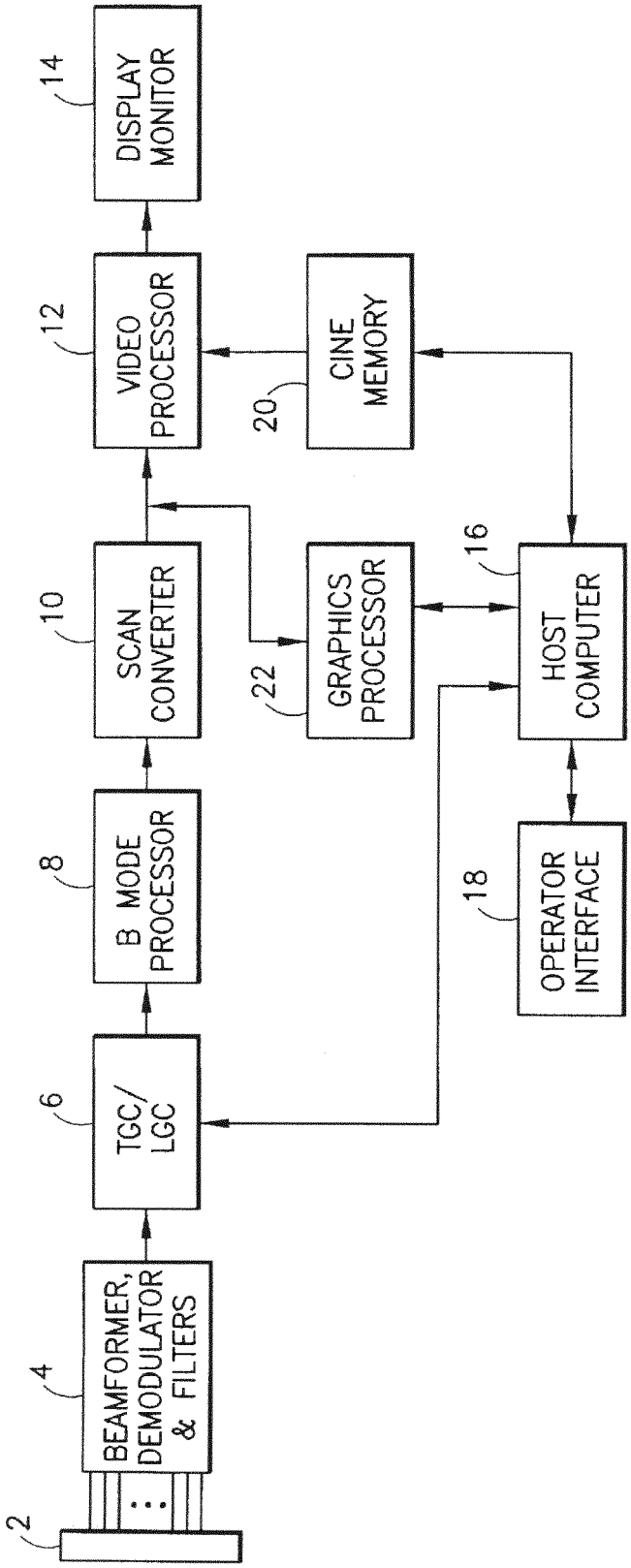

DISPLAY MONITOR
14
VIDEO PROCESSOR
12
CINE MEMORY
20
SCAN CONVERTER
10
GRAPHICS PROCESSOR
22
HOST COMPUTER
16
B MODE PROCESSOR
8
OPERATOR INTERFACE
18
TGC/ LGC
6
BEAMFORMER, DEMODULATOR & FILTERS
4
2

FIG. 1

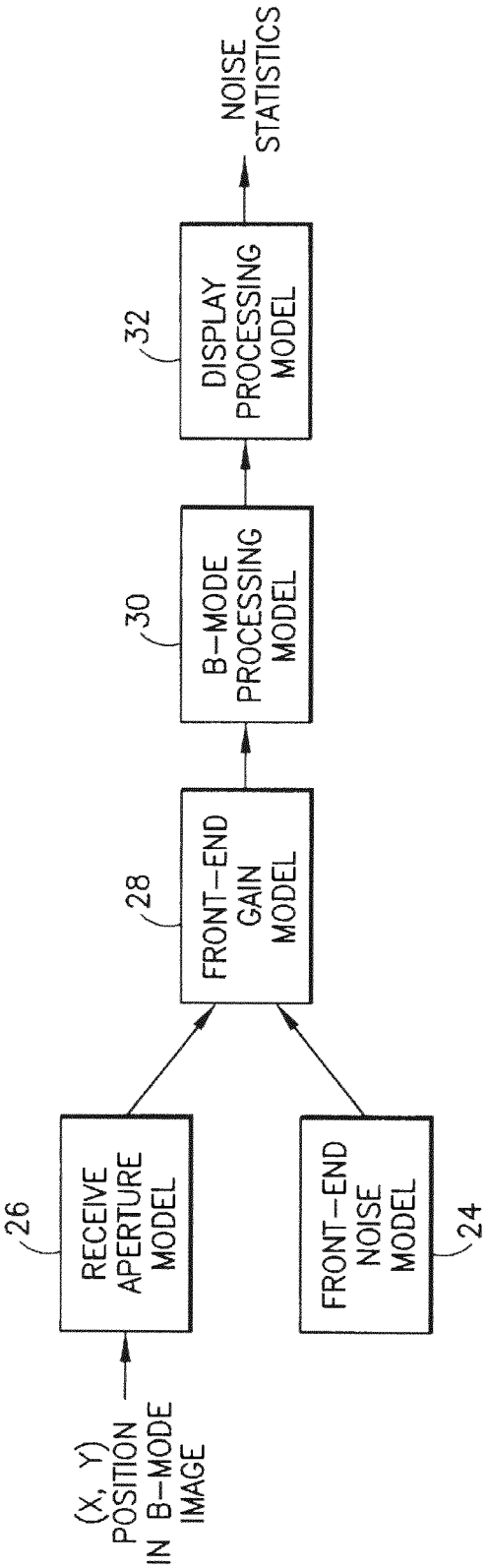

(X, Y) POSITION IN B-MODE IMAGE
RECEIVE APERTURE MODEL
26
FRONT-END NOISE MODEL
24
FRONT-END GAIN MODEL
28
B-MODE PROCESSING MODEL
30
DISPLAY PROCESSING MODEL
32
NOISE STATISTICS

FIG.2

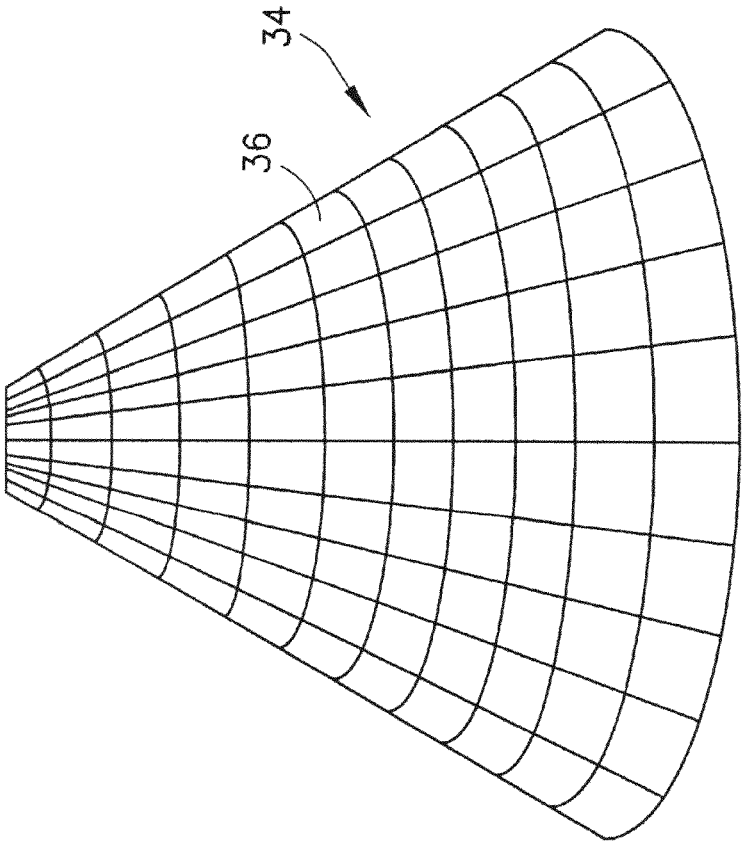


FIG.3

METHOD AND APPARATUS FOR AUTOMATIC TIME AND/OR LATERAL GAIN COMPENSATION IN B-MODE ULTRASOUND IMAGING

FIELD OF THE INVENTION

This invention generally relates to B-mode ultrasound imaging of biological tissues. In particular, the invention relates to methods for fine tuning a B-mode ultrasound image by adjusting the gain setting as a function of the axial and/or lateral position.

BACKGROUND OF THE INVENTION

In B-mode ultrasound imaging, two-dimensional images of tissue are created in which the brightness of a pixel is based on the intensity of the echo return. During conventional two-dimensional imaging, gain adjustments provide overall image changes. The gain is typically adjusted after beamforming and before signal processing, i.e., prior to envelope detection. Gain adjustment in the axial direction, known as "time gain compensation" (TGC), is carried out by increasing or decreasing gain as a function of depth. In addition, "lateral gain compensation" (LGC) can be used to adjust the gain setting as a function of lateral position.

The TGC block at the output of the beamformer is basically a depth-dependent gain control designed to compensate the received signal to correct for the attenuation caused by tissues at increasing depths. It is often set based on a nominal tissue attenuation factor (e.g., 0.5 dB/cm-MHz) and beam diffraction losses as a function of depth. The objective is to produce uniform tissue image brightness from the near field to the far field. In practice, the tissue attenuation properties may deviate from the assumed constant factor (or an application-dependent internal TGC curve), and may vary significantly with depth, especially if macroscopic structures and reflectors are present. Further, if the far-field regions are very noisy, it is desirable to suppress their pixel intensities for best overall image presentation. For these reasons, manual TGC adjustment is usually provided via a column of "slide pots" (potentiometers) or rotary knobs on the front panel, for different depth zones. The externally adjusted TGC for different depth zones is usually graphically displayed as a TGC curve in the monitor display. The TGC graphic is generated, for example, by a graphic processor as an overlay to the image display.

For cardiac sector imaging, the cardiac tissues/borders that run parallel to the ultrasound beam often do not produce strong echoes. Therefore, in addition to TGC, LGC adjustment has also proven useful for boosting cardiac borders within selected image sectors, while leaving the chambers dark. LGC allows the user to control gain in the lateral plane by adjusting the gain setting as a function of lateral position. For example, gain is controlled in small user-selected sectors across the image. LGC can be implemented at the same point as TGC in the B-mode processing path. A graph of the LGC curve similar to the TGC curve is also often displayed on the video monitor.

While state-of-the-art scanners provide the user with a host of selectable imaging parameters, including transmit frequency, acoustic output, external TGC and LGC controls, frame averaging level, dynamic range, edge-enhancing filters and video gray mapping, all of which can significantly affect the sensitivity, uniformity and feature enhancements of an image, the sonographer usually does not have the time (or training) to fully optimize all the available controls. To improve the ease-of-use and efficiency of the ultrasound examination, there is a need to automate some of the basic imaging parameter selection based on actual image data.

SUMMARY OF THE INVENTION

The present invention is a method for automating the external TGC and/or LGC adjustments based on the B-mode image data. The automatic gain adjustments are aimed at equalizing the mean signal intensities along the axial (for TGC) and/or lateral (for LGC) direction of the image, and suppressing any lateral band (for TGC) and/or sector (for LGC) that contains mostly noise. This automatic gain adjustment feature will reduce TGC or LGC adjustment time. Some additional manual adjustments (via the external TGC/LGC controls) can be made to further highlight edges or to fine tune the gain adjustments.

In accordance with the preferred embodiment, the automatic TGC/LGC adjustment method is implemented in software on a digital scanner. In practice, many variations in the basic system architecture are possible. In the preferred embodiment, the TGC/LGC functions are implemented between the beamformer and B-mode processor. In other system configurations, the TGC/LGC functions can be implemented in the analog front-end before the beamformer or after B-mode detection. In some conventional systems, the acoustic or R-θ data (before scan conversion) is stored in cine memory. The automatic TGC/LGC algorithm of the present invention can support all such standard architectural variations.

In accordance with the preferred embodiment of the invention, the automatic TGC/LGC adjustment method uses a noise model of the entire B-mode processing chain from the beamformer through the B-mode processor to the back-end video processor. Basically the noise model utilizes the fact that the primary noise source in a digital scanner lies in the front-end electronics (pre-amplifier), which can be modeled as white Gaussian noise whose RMS amplitude can be calibrated accurately (for normal operating temperature). Thus, by incorporating knowledge of the exact system bandwidths and gains at various points in the signal processing path, and of the display dynamic range setting and video gray mapping, the noise model can be used to predict the exact noise statistics (mean and probability distribution) in the B-mode image for any combination of internal (preset) TGC/LGC curve and front-panel gain settings.

In accordance with the preferred embodiments, an image frame of display pixel intensity values is divided into a regular grid of kernels by the host computer. The host computer then retrieves the current settings of all pertinent gain-related parameters for each kernel. A noise model is used to predict the mean noise level in each kernel. For each kernel, the host computer then calculates the mean (or total) pixel intensity and compares that to the predicted mean (or total) noise. [As used herein, the term "mean" means average.] Signal is deemed present in a kernel if its mean display pixel intensity is significantly above the predicted noise level. Otherwise the kernel is considered to contain only noise. For each row (sector), the kernels which contain signal are counted. If this number is less than a certain threshold, then that row (sector) is classified as "mostly noise". For each row (sector) whose signal kernel count is above the critical threshold, the host computer then computes the mean display pixel intensity, i.e., "row (sector) mean", of all kernels that contain signal (i.e. excluding kernels that do not contain signal). Based on a given optimal mean gray-scale level for the B-mode image display, the host computer then determines the gain adjustment for each

row (sector) which will shift the gray-scale level (based on the current gray map settings) corresponding to the row (sector) mean to the optimal gray-scale level. The required gain adjustment can be computed in decibels using the noise model, which should take into account the current dynamic range and gray map settings. The gain adjustment is then applied to the raw acoustic data (RF or baseband) for each row (sector) to equalize the row (sector) means across the entire image.

Optionally, for the rows (sectors) which have been classified as "mostly noise," the row (sector) gain can be automatically reduced to suppress the noise.

In accordance with the preferred embodiments of the invention, either or both of the TGC and the LGC can be automated.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic showing a block diagram of an ultrasound imaging system in accordance with the preferred embodiments of the invention.

FIG. **2** is a schematic showing a block diagram of a B-mode image noise model used in performing the TGC and LGC in accordance with the preferred embodiments of the invention.

FIG. **3** is a schematic depicting an ultrasound sector image which has been divided into a regular grid of kernels for use in TGC and LGC.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An ultrasound imaging system in accordance with one preferred embodiment of the invention is generally depicted in FIG. **1**. The main data path begins with the analog RF inputs to the beamformer board **4** from the transducer **2**. The beamformer board **4** comprises a beamformer, a demodulator and filters. The beamformer's signal inputs are the low-level analog RF signals from the transducer elements. The beamformer is responsible for analog-to-digital conversion and for transmit and receive beamforming. The demodulator receives the acquired data samples and outputs two summed digital baseband I and Q receive beams. These acoustic data samples are derived from the reflected ultrasound from respective focal zones of the transmitted beams. The I and Q acoustic data from the demodulator is sent to respective FIR filters which are programmed with filter coefficients to pass a band of frequencies preferably centered at the fundamental frequency f_0 of the transmit waveform or a (sub)harmonic frequency thereof.

In accordance with the preferred embodiment of the invention, vectors of filtered I and Q acoustic data are input to a TGC/LGC block **6**, which provides time gain and/or lateral gain compensation. Time gain compensation fine tunes the image in the axial direction by increasing or decreasing gain as a function of depth (time) for all received vectors. Lateral gain compensation fine tunes the image in the lateral direction by increasing or decreasing gain as a function of lateral position (beam or vector position). In the former case, gain is controlled in small rows of the image. In the latter case, gain is controlled in small sectors of the image.

Each I and Q vector input to TGC/LGC block **6** corresponds to a respective receive beam. For time gain compensation, block **6** applies depth-dependent digital gains to an acoustic data vector. For lateral gain compensation, block **6** applies angle-dependent digital gains to respective vectors of acoustic data. During scanning, successive vectors (A-lines) are input to TGC/LGC block **6** for gain compensation. In the case where both TGC and LGC are provided, a respective gain can be automatically applied to each point along a vector, the gain being a function of depth (i.e., range R) and vector angle (i.e., transmit beam angle θ).

The acoustic data output from the TGC/LGC block is sent to the B-mode processor **8**. The B-mode processor **8** converts the I and Q acoustic data from TGC/LGC block **6** into a log-compressed version of the signal envelope. The B-mode function images the time-varying amplitude of the envelope of the signal as a gray scale. The envelope of a baseband signal is the magnitude of the vector which I and Q represent. The I,Q phase angle is not used in the B-mode display. The magnitude (i.e., intensity) of the signal is the square root of the sum of the squares of the orthogonal components, i.e., $(I^2+Q^2)^{1/2}$.

The B-mode intensity data is output to a scan converter **10** comprising a B-mode acoustic line memory followed by an X-Y display memory (not shown). The acoustic line memory accepts the processed vectors of B-mode intensity data and interpolates where necessary. The B-mode acoustic line memory also performs the coordinate transformation of the B-mode intensity data from polar coordinate (R-θ) sector format or Cartesian coordinate linear format to appropriately scaled Cartesian coordinate display pixel intensity data, which is stored in the X-Y display memory.

The scan-converted frames are passed to a video processor **12**, which maps the pixel intensity data to a gray-scale mapping for video display. A conventional ultrasound imaging system typically employs a variety of gray maps, which are simple transfer functions of the raw intensity data to display gray-scale levels. The gray-scale image frames are then sent to the display monitor **14** for display.

The B-mode images displayed by monitor **14** are produced from an image frame of data in which each datum indicates the intensity or brightness of a respective pixel in the display. An image frame may, e.g., comprise a 256×256 data array in which each display pixel intensity datum is an 8-bit binary number that indicates pixel brightness. Each pixel has an intensity value which is a function of the backscatter cross section of a respective sample volume in response to interrogating ultrasonic pulses and the gray map employed. The displayed image represents the tissue and/or blood flow in a plane through the body being imaged.

Successive frames of display pixel intensity data are stored in a cine memory **20** on a first-in, first-out basis. The cine memory stores the pixel intensity data which has already been combined with the TGC and all other graphic data. The cine memory also stores the pixel intensity data which is already converted in the first portion of the video processor into video frame rate, but before gray mapping. Storage can be continuous or as a result of an external trigger event. The cine memory **20** is like a circular image buffer that runs in the background, capturing image data that is displayed in real time to the user. When the user freezes the system (by operation of an appropriate device on the operator interface **18**), the user has the capability to view image data previously captured in cine memory.

System control is centered in a host computer **16**, which accepts operator inputs through the operator interface **18** (e.g., a control panel) and in turn controls the various subsystems. The host computer **16** performs system level control functions. A system control bus (not shown) provides the interface from the host computer to the subsystems. A scan controller (not shown) provides real-time

(acoustic vector rate) control inputs to the various subsystems. The scan controller is programmed by the host computer with the vector sequences and synchronization options for acoustic frame acquisitions. Thus, the scan controller controls the beam distribution and the beam density. The scan controller transmits the beam parameters defined by the host computer to the subsystems via a scan control bus (not shown).

The conventional system has the capability to superimpose graphical symbols on any ultrasound image. The superimposition of graphics on the image frame is accomplished in the video processor **12**, which receives the ultrasound image frame from the X-Y display memory in the scan converter **10** and the graphics data from a graphics display memory (not shown). The graphics data is processed and input into the graphics display memory by a graphics processor **22** which is synchronized with the other subsystems by the host computer.

The automated TGC/LGC adjustment method can be implemented in software by the host computer. One key component of the method is a noise model of the entire B-mode processing chain from the beamformer through the B-mode processor to the back-end video processor. For a given position (x, y) in the B-mode image frame, the image noise model is used to predict the noise level (as a B-mode intensity or gray-scale level) at that position. For contemporary digital scanners, the image noise model consists of several key components, the details of which depend on the specific subsystem design for a particular scanner. The noise/gain calculations involved in each component are standard practices in systems design, so only the main function of each component are described in the following.

A B-mode image noise model suitable for use in the preferred embodiment of the invention is generally depicted in FIG. **2**. The front-end noise model (block **24**) computes the Gaussian noise level generated by the front-end electronics (e.g., the pre-amplifier) in a single receive channel and any quantization noise associated with analog-to-digital conversion. The analog electronics noise is often referred to as thermal noise and can be calibrated accurately for a given temperature range. Depending on the electrical impedance of the transducer which is connected to the front end, the thermal noise may or may not have a flat spectral power density.

The number of receive channels contributing noise is dependent on the receive aperture size, which is computed by the receive aperture model (block **26**) based on the known aperture control parameters (i.e., F number and shading) for the given probe and (x, y) position.

The front-end gain model (block **28**) computes the total noise from all independent receive channels, and incorporates the effects of all filtering gains in the beamformer, including any TGC/LGC.

The B-mode processing model (block **30**) adjusts the noise for the noise gains that occur in the B-mode detector and filters including scan conversion. Standard noise theory indicates that the detected envelope of Gaussian noise obeys the Rayleigh probability distribution, which is completely specified by its mean.

The display processing model (block **32**) accounts for the effects of logarithmic compression and gray mapping, and outputs the predicted noise distribution at the inputted (x, y) position in the image.

The above-described noise model is run by the host computer. Prior to running the noise model, the host computer needs to read out all pertinent internal and external system settings, such as the current TGC curve, transmit focal zone positions, image depth, display dynamic range setting and gray mapping setting. The host computer then feeds these parameters into the various components of the image noise model.

The host computer also performs the automatic TGC/LGC algorithm. It is assumed that an image of the region of interest is currently displayed on the video monitor. The automatic TGC/LGC can be activated via a single button (or soft-key). The main steps in the TGC/LGC algorithm in accordance with one preferred embodiment are outlined as follows.

In response to activation of the automatic TGC/LGC function, the image is frozen momentarily to allow one to several most recent image frames to be saved to cine memory, which can then be read out by the host computer for analysis. If more than one is used, a mean is taken to reduce statistical variations before image analysis. The size of the image (single or mean) is determined, and is then divided into a regular grid **34** of kernels **36** as shown in FIG. **3**, where the number of rows and sectors (columns) of kernels in the grid should be at least as large as the number of the respective TGC and LGC knobs/slide pots on the front panel. The kernel dimensions are defined by equal range and vector angle spacings for a sector or curvilinear scan (as shown in FIG. **3**), and they are rectangles or squares for a linear scan.

The host computer retrieves the current settings of all pertinent gain-related parameters, such as internal TGC, receive aperture and B-mode processor gains, for each kernel within the grid. These can usually be read out from other system programs or computed from known system parameters. These parameter values are input to the noise model to predict the mean noise level in each kernel of the grid.

For each kernel in the grid the host computer compares the mean (or total) pixel intensity to the predicted mean (or total) noise. Signal is present if the mean pixel intensity of a kernel is significantly (e.g., 10 dB) above the predicted mean noise level for that same kernel. Otherwise the kernel is considered to contain noise only.

For automatic TGC compensation, the following steps are performed. For each row, the kernels which contain signal are counted. If this number is less than a certain threshold (e.g., 10% of the total number of kernels in a row), then that row is classified as "mostly noise." For each row whose signal kernel count is above the critical threshold, the mean pixel intensity of all kernels that contain signal (i.e. excluding kernels that do not contain signal) is computed. This gives the "row mean", which can be converted to a gray-scale level by the host computer referring to the current gray mapping settings. Based on a given optimal mean gray-scale level for the B-mode image display (e.g., for an 8-bit video gray scale, the optimal mean gray-scale level may be 200), the host computer then determines the gain adjustment for each row which will shift the row mean gray-scale level to the optimal gray-scale level. The gain adjustment required can be computed using the noise model, which should take into account the current dynamic range and gray map settings. In fact, it should be exactly equivalent to adjusting the external TGC knobs, which may affect the front-end and/or B-mode processor gains depending on the system architecture. In the preferred embodiment, the gain adjustments for each row are applied in block **6** (see FIG. **1**) to equalize the row means across the entire image. This is effected exactly as if the user were applying the same gain

adjustments via the front-panel TGC slide pots or knobs. Optionally, for the rows which have been classified as "mostly noise," the row gain can be automatically turned down to suppress the noise (by shifting down its mean gray-scale level by a fixed amount or shifting it down towards zero grayscale level).

For automatic LGC, the procedure is exactly parallel to that for automatic TGC described above. For each sector (for sector scans) or column (for linear scans), the kernels which contain signal are counted. If this number is less than a certain threshold (e.g., 10% of the total number of kernels in a sector or column), then that sector (column) is classified as "mostly noise." For each sector (column) whose signal kernel count is above the critical threshold, the mean pixel intensity of all kernels that contain signal (i.e., excluding kernels that do not contain signal) is computed. This gives the "sector (column) mean", which can be converted to a gray-scale level by the host computer referring to the current gray mapping settings. Based on the optimal mean gray-scale level previously described, the host computer then determines the gain adjustment for each sector (column) which will shift the sector (column) mean gray-scale level to the optimal grayscale level. Again the required gain adjustment is computed using the noise model, taking into account the current dynamic range and gray map settings. Again, this should be exactly equivalent to adjusting the external LGC knobs. The gain adjustments for each sector (column) are applied in block **6** (see FIG. **1**) to equalize the sector (column) means across the entire image. Again, for those sectors (columns) which have been classified as "mostly noise," the sector (column) gain can be automatically turned down to suppress the noise.

The graphics processor **22** (see FIG. **1**) supplies graphic data to the video processor **12** for display on the monitor **14**. This graphic data is designed to indicate the magnitudes of the automatic gain adjustments and the corresponding relative positions in the image. Preferably, the graphic data take the form of TGC and LGC curves. The TGC curve and LGC curve graphics in the display monitor are updated automatically by the graphics processor. A different line-type can be used to display the automatic TGC and LGC curves so they can be distinguished from the curves corresponding to the TGC and LGC slide pot positions. For example, if automatic TGC is activated, a solid curve can be used to display the active TGC curve and a dashed line for the manually set TGC curve. If automatic TGC is turned off, the dashed curve reverts back to a solid curve to indicate that the slide-pot TGC curve is now active again.

In accordance with the preferred embodiment, automatic TGC and LGC are both applied by the host computer to control gain in the lateral and axial planes. Alternatively, the host may apply only one or the other type of gain compensation.

The foregoing preferred embodiments have been disclosed for the purpose of illustration. Variations and modifications of the concept of the invention will be readily apparent to persons skilled in the art. For example, the automated TGC/LGC functions of the invention are not limited to being implemented between the beamformer and B-mode processor, but instead can be implemented in the analog front-end before the beamformer or after B-mode detection. Moreover, the invention is not limited to processing of display intensity data. For systems in which the acoustic or R-θ data (before scan conversion) is stored in cine memory, the automatic TGC/LGC algorithm can be applied to the raw acoustic data instead of the display intensity data. All such variations and modifications are intended to be encompassed by the claims set forth hereinafter.

As used in the claims, the term "acoustic data" refers to the received signal at any point between the transducer and the scan converter; the term "pixel intensity data" refers to the scan-converted signals prior to gray mapping; and the term "gray-scale level data" refers to the gray-mapped pixel intensity data output to the display device. The term "kernel having signal", as used in the claims, means a kernel having a mean pixel intensity which is greater than the predicted mean noise level for that same kernel by a predetermined quantity. It will also be appreciated that calculation of the total pixel intensity value within a kernel is the equivalent of calculation of the mean pixel intensity, as recited in the claims.

What is claimed is:

1. A system for imaging biological tissues, comprising:

an ultrasound transducer array comprising a multiplicity of transducer elements;

a transmit beamformer for pulsing said transducer array to transmit ultrasound beams in first and second scans;

a receive beamformer for forming receive beams of acoustic data derived from echo signals detected by the transducer array subsequent to said transmissions;

a signal processing chain for converting said acoustic data into first and second image frames of pixel intensity data corresponding to said first and second scans respectively, said signal processing chain comprising a gain compensation component for adjusting the gain of the acoustic data as a function of gain adjustments;

a computer programmed to determine said gain adjustments as a function of said first image frame of pixel intensity data and the current settings of all pertinent gain-related system parameters in accordance with a noise model, and transmit said gain adjustments to said gain compensation component in time to adjust the gain of the acoustic data acquired from said second scan;

a video processor for converting said image frame of pixel intensity data into an image frame of gray-scale level data; and

a display device for displaying an image representing said image frame of gray-scale level data, wherein said computer is programmed to perform the following steps:

(a) dividing said first image frame of pixel intensity data into a regular grid of kernels forming a plurality of rows;

(b) retrieving the current settings of all pertinent gain-related parameters for each kernel;

(c) predicting the mean noise level in each kernel using said noise model;

(d) calculating the mean pixel intensity for each kernel;

(e) comparing the predicted mean noise level with the calculated mean pixel intensity for each kernel;

(f) for each row satisfying a predetermined condition, determining a mean pixel intensity of all kernels having signal to form a row mean;

(g) based on an optimal mean gray-scale level, determining the gain adjustment for each row which will shift the gray-scale level corresponding to the respective row mean to said optimal gray-scale level; and

(h) sending said gain adjustments to said gain compensation component.

2. The system as recited in claim **1**, wherein said computer is further programmed to determine the respective downward gain adjustment which will suppress the noise for each

row whose count of kernels having signal is less than said critical threshold.

3. A system for imaging biological tissues, comprising:

an ultrasound transducer array comprising a multiplicity of transducer elements;

a transmit beamformer for pulsing said transducer array to transmit ultrasound beams in first and second scans;

a receive beamformer for forming receive beams of acoustic data derived from echo signals detected by the transducer array subsequent to said transmissions;

a signal processing chain for converting said acoustic data into first and second image frames of pixel intensity data corresponding to said first and second scans respectively, said signal processing chain comprising a gain compensation component for adjusting the gain of the acoustic data as a function of gain adjustments;

a computer programmed to determine said gain adjustments as a function of said first image frame of pixel intensity data and the current settings of all pertinent gain-related system parameters in accordance with a noise model, and transmit said gain adjustments to said gain compensation component in time to adjust the gain of the acoustic data acquired from said second scan;

a video processor for converting said image frame of pixel intensity data into an image frame of gray-scale level data; and

a display device for displaying an image representing said image frame of gray-scale level data, wherein said computer is programmed to perform the following steps:

(a) dividing said first image frame of pixel intensity data into a regular grid of kernels forming a plurality of sectors;

(b) retrieving the current settings of all pertinent gain-related parameters for each kernel;

(c) predicting the mean noise level in each kernel using said noise model;

(d) calculating the mean pixel intensity for each kernel;

(e) comparing the predicted mean noise level with the calculated mean pixel intensity for each kernel;

(f) for each sector satisfying a predetermined condition, determining a mean pixel intensity of all kernels having signal to form a sector mean;

(g) based on an optimal mean gray-scale level, determining the gain adjustment for each sector which will shift the grayscale level corresponding to the respective sector mean to said optimal gray-scale level; and

(h) sending said gain adjustments to said gain compensation component.

4. The system as recited in claim 3, wherein said computer is further programmed to determine the respective downward gain adjustment which will suppress the noise for each sector whose count of kernels having signal is less than a critical threshold.

5. A system for imaging biological tissues, comprising:

an ultrasound transducer array comprising a multiplicity of transducer elements;

a transmit beamformer for pulsing said transducer array to transmit ultrasound beams in first and second scans;

a receive beamformer for forming receive beams of acoustic data derived from echo signals detected by the transducer array subsequent to said transmissions;

a signal processing chain for converting said acoustic data into first and second image frames of pixel intensity data corresponding to said first and second scans respectively, said signal processing chain comprising a gain compensation component for adjusting the gain of the acoustic data as a function of gain adjustments;

a computer programmed to determine said gain adjustments as a function of said first image frame of pixel intensity data and the current settings of all pertinent gain-related system parameters in accordance with a noise model, and transmit said gain adjustments to said gain compensation component in time to adjust the gain of the acoustic data acquired from said second scan;

a video processor for converting said image frame of pixel intensity data into an image frame of gray-scale level data; and

a display device for displaying an image representing said image frame of gray-scale level data, wherein said computer is programmed to perform the following steps:

(a) dividing said first image frame of pixel intensity data into a regular grid of kernels having a plurality of columns;

(b) retrieving the current settings of all pertinent gain-related parameters for each kernel;

(c) predicting the mean noise level in each kernel using said noise model;

(d) calculating the mean pixel intensity for each kernel;

(e) comparing the predicted mean noise level with the calculated mean pixel intensity for each kernel;

(f) for each column satisfying a predetermined condition, determining a mean pixel intensity of all kernels having signal to form a column mean;

(g) based on an optimal mean gray-scale level, determining the gain adjustment for each column which will shift the grayscale level corresponding to the respective column mean to said optimal gray-scale level; and

(h) sending the gain adjustments to said gain compensation component.

6. The system as recited in claim 5, wherein said computer is further programmed to determine the respective downward gain adjustment which will suppress the noise for each column whose count of kernels having signal is less than a critical threshold.

7. A method for automatically adjusting gain in an ultrasound imaging system, comprising the steps of:

(a) dividing an image frame of pixel intensity data into a regular grid of kernels forming a plurality of sets of aligned kernels;

(b) retrieving the current settings in said ultrasound imaging system of all pertinent gain-related parameters for each kernel;

(c) predicting the mean noise level in each kernel using a noise model;

(d) calculating a function of the pixel intensity for each kernel;

(e) comparing the predicted mean noise level with the calculated pixel intensity function for each kernel;

(f) for each kernel set satisfying a predetermined condition, determining a mean pixel intensity of all kernels having signal to form a kernel set mean;

(g) based on an optimal mean gray-scale level, determining the gain adjustment for each kernel set which will

shift the gray-scale level corresponding to the respective kernel set mean to said optimal gray-scale level; and

(h) adjusting the gain in accordance with said gain adjustments during subsequent operation of said ultrasound imaging system.

8. The method as recited in claim **7**, wherein said function is mean pixel intensity.

9. The method as recited in claim **7**, wherein said function is total pixel intensity.

10. The method as recited in claim **7**, wherein each kernel set forms a respective row in said grid.

11. The method as recited in claim **7**, wherein each kernel set forms a respective sector in said grid.

12. The method as recited in claim **7**, wherein each kernel set forms a respective column in said grid.

13. The method as recited in claim **7**, wherein said gain adjustments are varied along each vector of acoustic data.

14. The method as recited in claim **7**, wherein said gain adjustments are varied across vectors of acoustic data.

15. The method as recited in claim **7**, further comprising the step of determining a respective down-ward gain adjustment which will suppress the noise for each kernel set whose count of kernels having signal is less than a critical threshold.

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